CALIFORNIA GEOLOGY

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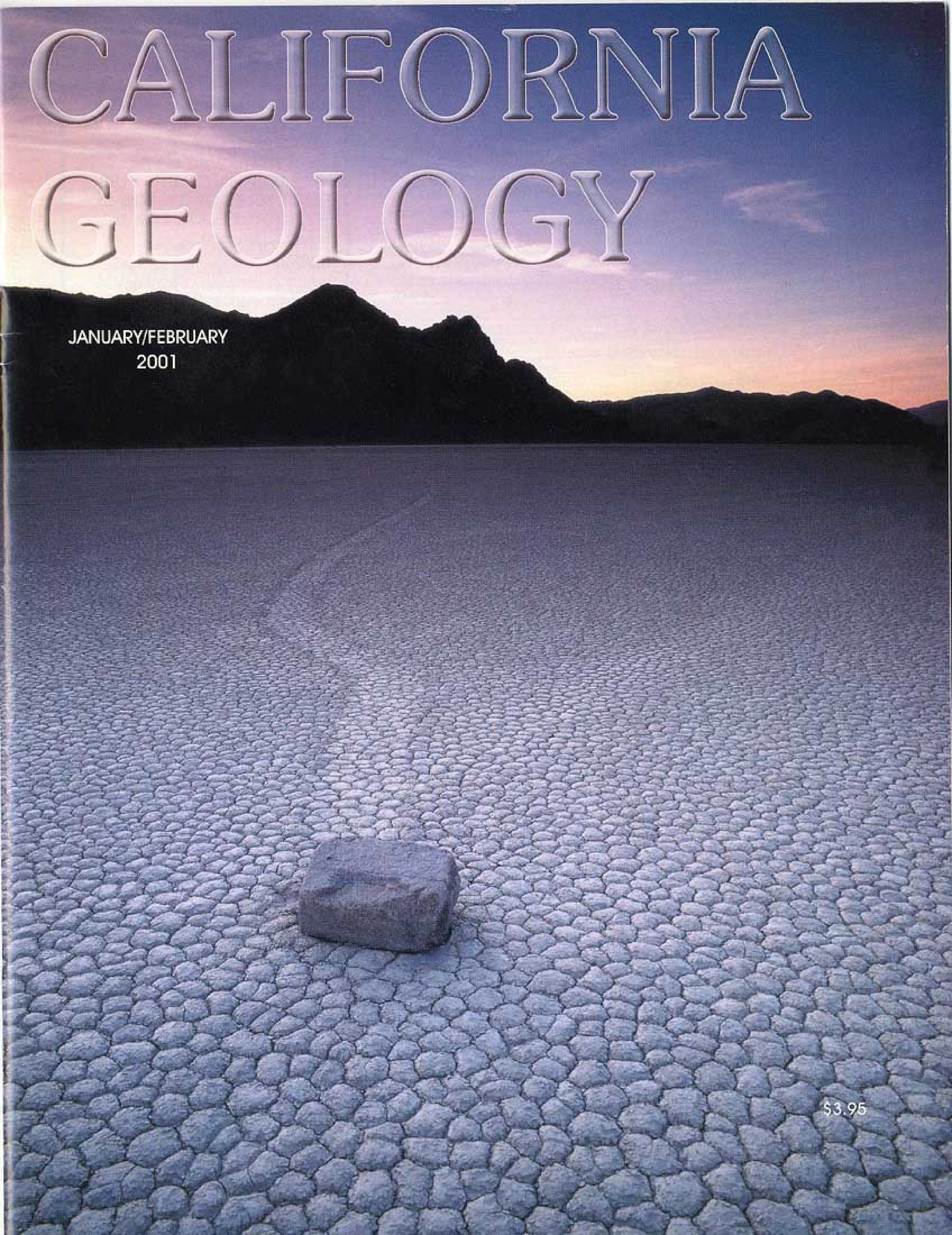

CALIFORNIA GEOLOGY

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CD 2000-003. DIGITAL IMAGES OF OFFICIAL MAPS OF THE ALQUIST-PRIOLO EARTHQUAKE FAULT ZONES OF CALIFORNIA, SOUTHERN REGION. By William Bryant. 2000. $30.00.

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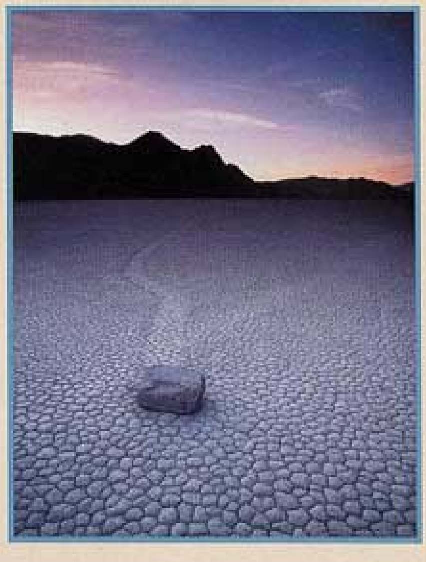
Acrobat Reader© is required to view the files. To order CD 2000-003, use the form on page 33.



Cover Photo: End of the trail? Looking northwest from the southern part of Racetrack Playa, Death Valley National Park. Ubehebe Peak is silhouetted against the setting sun, and a lone playa rock enjoys a respite at the end of its trail. The exact mechanisms responsible for these trails continue to puzzle geologists who employ some of the latest methods to study them.
Photo by Phil Kember © 2001, www.DeathValleyphoto.com.

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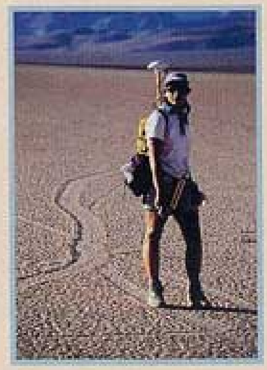

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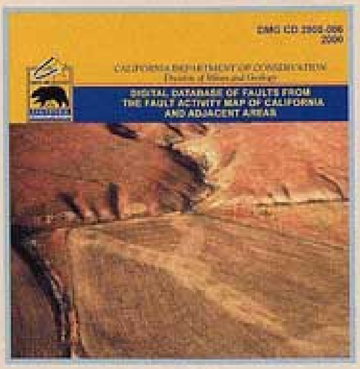

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USING NEW TECHNOLOGY TO SOLVE AN OLD MYSTERY

Mapping the "Sliding" Rocks of Racetrack Playa, Death Valley National Park, California

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INTRODUCTION

Rocks ranging from pebbles to boulders, some with masses up to 320 kilograms, apparently have been sliding across a remote playa (aptly named Racetrack Playa) in Death Valley National Park (DVNP) (Figure 1). Although this phenomenon has been taking place in modern times, remarkably, it has never been witnessed. Telltale signs of this curious activity have been inscribed in the fine-grained sediment on the playa surface as long grooves (Photo 1). Many of these grooves (some as long as 880 meters [m]) end at a rock, thus hinting at the trail's origin. Given the nature of these trails, with their smooth rounded levees, it's not difficult to imagine that they were gouged out of wet, soft mud by sliding rocks, and since preserved as "fossil wakes" by the desiccating climate.

The earliest description of these trails was reported in 1915 by a prospector named Joseph Crook. Crook brought his wife along on one prospecting trip so that she could observe the unusual trails firsthand. Mrs. Crook was so intrigued that she marked the position of one of the larger boulders. Sometime between that visit and a subsequent prospecting trip, the boulder slid away from its marked position.

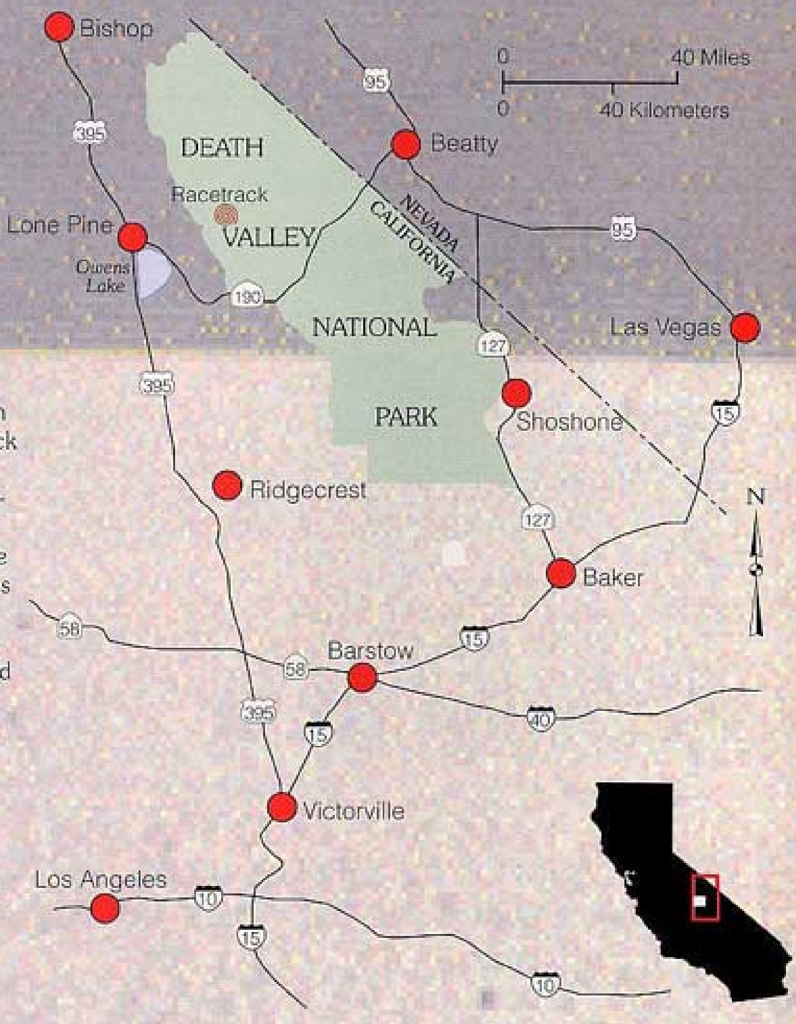


Figure 1. Racetrack Playa is in the northern part of Death Valley, National Park.

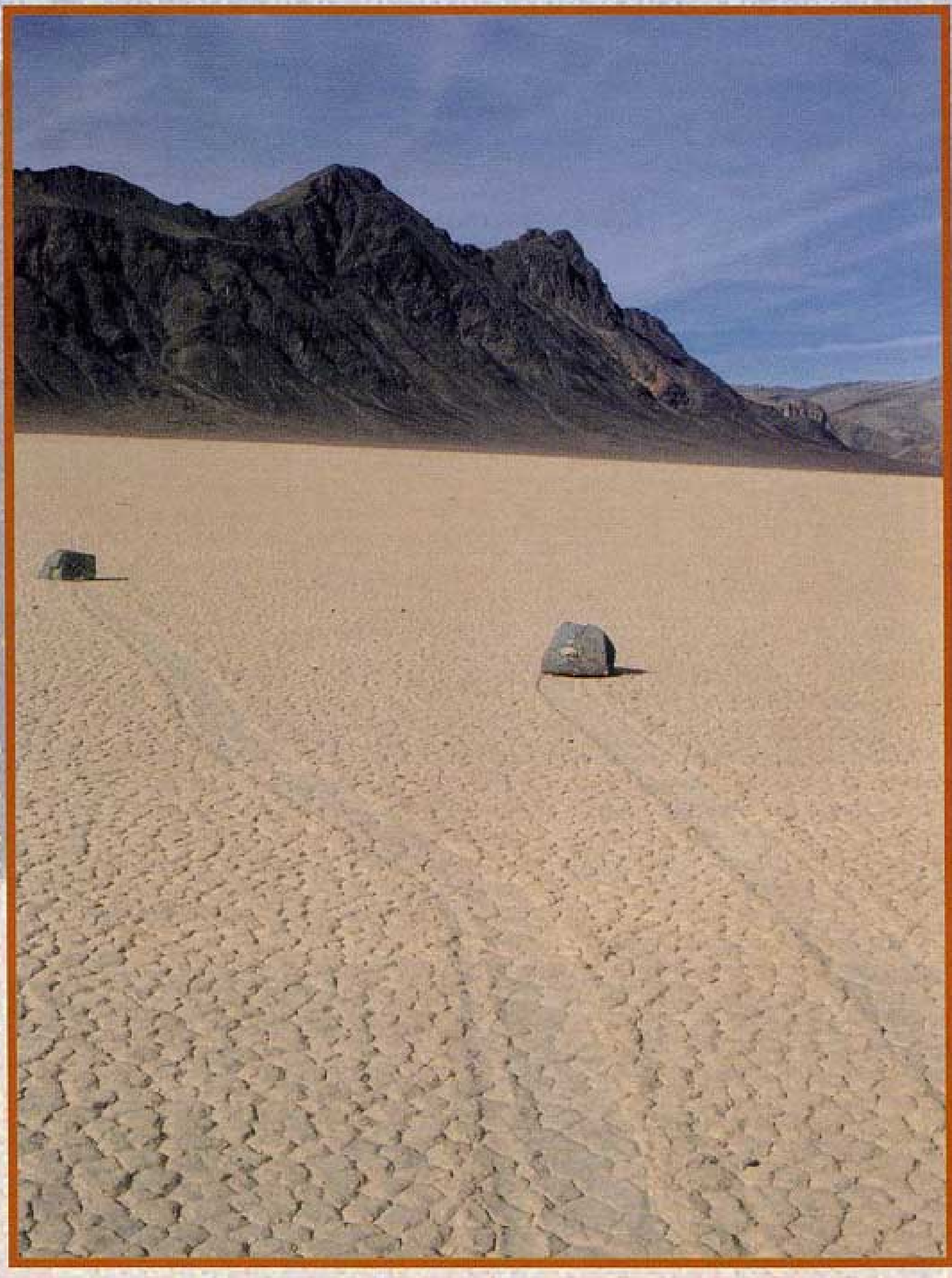


Photo 1. Two northwest-trending trails inscribed by "sliding" rocks on the Racetrack Playa, Death Valley National Park, California. *Photo by Paula Messina.*

The earliest geologic interpretations of the phenomenon were proposed by McAllister and Agnew (1948); McAllister encountered the rocks while conducting field work, which resulted in the first U.S. Geological Survey geologic map of the area (McAllister, 1956). McAllister and Agnew proposed that these "playa furrows" were gouged by rock fragments, or "playa scrapers," which were propelled over the wet playa surface by strong winds, specifically erratic whirlwinds. Since then, Racetrack Playa's unusual "sliding rocks" have been the focus of several mapping projects (Sharp and Carey, 1976; Reid and others, 1995; Sharp and others, 1996; Messina, 1998). And although the consensus is that the trails are inscribed in wet mud by moving rocks, disagreement and debates continue as to the exact mechanism that allows these rocks to move over the playa's surface. Our 1996 survey of the rocks and their trails will hopefully lead to a solution of this ongoing mystery.

PHYSICAL SETTING

Playas form the flat floor of enclosed desert basins. Racetrack is just one of dozens of playas that dot the U.S. southwest desert where rainfall by definition is sparse (Racetrack Playa's annual precipitation ranges from 7 to 10 centimeters [cm]). Occasionally, during wet years, these basins fill with runoff and fine-grained sediment forming shallow, ephemeral, or short-lived, lakes underlain by mud, silt and sand. At Racetrack Playa, historical records show that a particularly rainy winter in 1950-1951 formed a lake 25 cm deep; today however, it is usually dry. (This was not the case as recently as 2000 years ago when a wetter climate prevailed and a more permanent or perennial lake occupied Racetrack Playa.)

Racetrack Playa's western margin lies at the base of Ubehebe Peak's talus apron. From this base at 1,131 m in elevation, the slope rises rather steeply to 1,710 m at Ubehebe Peak's summit. The playa's surface is rather typical of other California desert playas: polygons of hard, desiccated sediments (24% fine sand; 41% silt; 35% clay) cover the 1,650-acre plain (Photo 2). The playa's surface is also not perfectly horizontal: it is about 5 cm higher in the north than in the south. Interrupting this otherwise featureless surface and protruding over 20 m above the dried muds in the northern part of Racetrack Playa is an 'island' of weathered quartz monzonite (type of granite) aptly known as the "Grandstand" (Photo 3).

Many of our observations of the playa surface only deepened the mystery of what we already know about the trails. For example, the majority of trails were made by rocks moving in a preferred southwest to northeast direction (and therefore slightly uphill). Furthermore, previous workers estimated that some rocks were moving as swiftly as 2 m per second (Sharp and Carey, 1976) based on fossilized splash marks and petrified bow waves (like those formed in water at the bow of a moving boat). Obviously, these clues only lead to more questions; the main one being, what enables these rocks to slide?

WITH OR WITHOUT ICE

Generally, there are two camps of thought or hypotheses for the cause of Racetrack's sliding rocks. Both assume the wind as a factor; however, one group maintains that wind alone pushes the rocks along (McAllister and Agnew, 1948; Clements, 1952; Kirk, 1952; Bradley, 1963; Sharp and Carey, 1976; Bacon, Cahill and Tombrello, 1996), while the other maintains that ice is an important factor (Shelton, 1953; Stanley, 1955; Schumm, 1956; Sharp, 1960; Reid and others, 1995). The wind-only group contends that wind speeds on the Racetrack must at least occasionally be great enough to overcome the rocks' frictional resistance to sliding, which would be minimized when the playa surface is wet and slick. The other camp envisions a cohesive, extensive ice sheet as a more logical mechanism. They defend the ice-floe hypothesis by noting ice blankets occasionally form on the Racetrack; some sheets have been as thick as 10 cm (Stanley, 1955). If rocks are embedded in a layer of ice, they reason, it's a good possibility that wind can move these "ice rafts," dragging rocks along and in turn scraping their trails on the underlying clays (Figure 2). The ice raft explanation was favored by survey teams that mapped parallel trails (Stanley, 1955), which were sometimes separated by several hundred meters (Reid and others, 1995). Ice rafting is also supported by those who, by experimental evidence and theoretical modeling, deduced that the playa's surface could never be slick enough to support the traction of massive materials under typical wind conditions (Schumm, 1956; Sharp, 1960; Reid and others, 1995).

To test the ice raft hypothesis, in 1976, Robert Sharp and Dwight Carey of Cal Tech and University of California, Los Angeles (UCLA), respectively, conducted an experiment on Racetrack Playa (Sharp and Carey, 1976). They built a "corral" composed of seven widely-spaced metal stakes arranged in a circle around several stones. Had an ice sheet formed, the stakes would have caused it to fracture upon any wind-induced motion. Surprisingly, upon subsequent visits, they found that one of the rocks had moved out of the corral, while the others remained in place (Photo 4). If ice played an integral role, this observation would be difficult to explain.

TRAILBLAZING ROCKS—MAPPING THEIR MOVEMENT

To gain a better picture of the sliding rocks and their trails, a number of limited mapping surveys had previously been conducted (Kirk, 1952; Stanley, 1955; Sharp and Carey, 1976; Reid and others, 1995). This work relied on conventional survey equipment (theodolites, levels, etc.) and methods, which require a sizable field crew and several

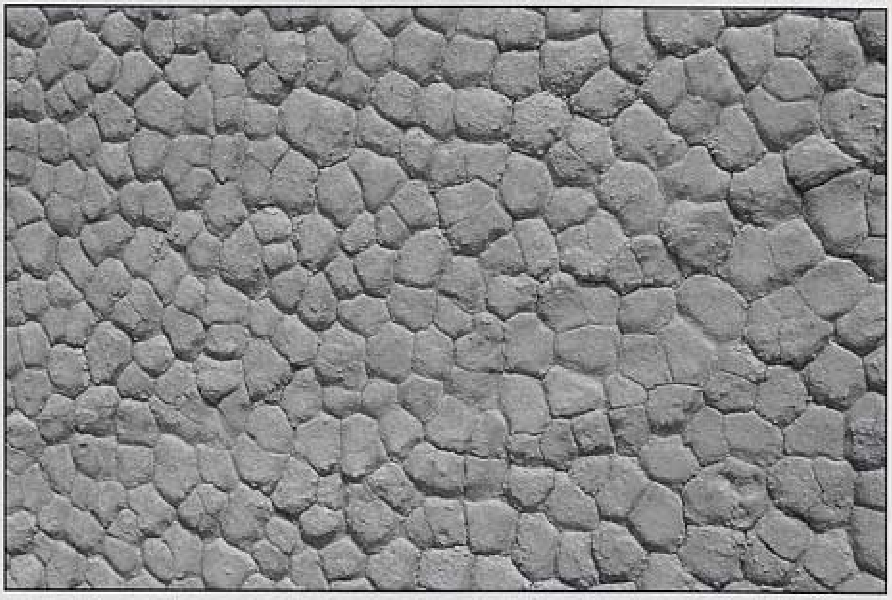


Photo 2. Desiccation polygons form in the fine-grain sediments on the Racetrack Playa's surface. Telltale evidence of sliding rock activity is also shown as slightly inscribed trail. *Photo by Paula Messina.*

Photo 3. A view of the northern end of the Racetrack, looking southeast from the Ubehebe Peak Trail. Note the Grandstand, a prominent monolith protruding through the playa sediments. The distant range is the Cottonwood Mountains, the northern extent of the Panamint Range. *Photo by Paula Messina.*

weeks' work. Given the extreme conditions on the playa (daytime temperatures can be below-freezing in winter and as high as 115°F during summer months), and the physical and legal obstacles, these early surveys included only a portion of the population of sliding rocks and their trails. Specifically, Kirk (1952) surveyed 12 rocks; 30 for Sharp and Carey, (1976); Reid and others, (1995) surveyed greater than 23 rocks, and Stanley, (1955) has an unspecified number. With even these limited surveys, a number of useful and interesting observations were made. Kirk (1952) and Sharp and Carey (1976) showed a predominant north-northeasterly heading for the majority of stone-trail combinations they mapped. Stanley (1955) devoted some of his analyses to a group of rock-trails that apparently moved almost due-south of their starting points. An interesting observation by Kirk (1952) noted that neither did the largest (therefore, heavi-

Figure 2. Are sliding rocks slaves to ice floes? This illustrates the hypothesis that rocks on Racetrack Playa can be trapped in ice sheets and are thus aided in sliding activity. *By Paula Messina.*

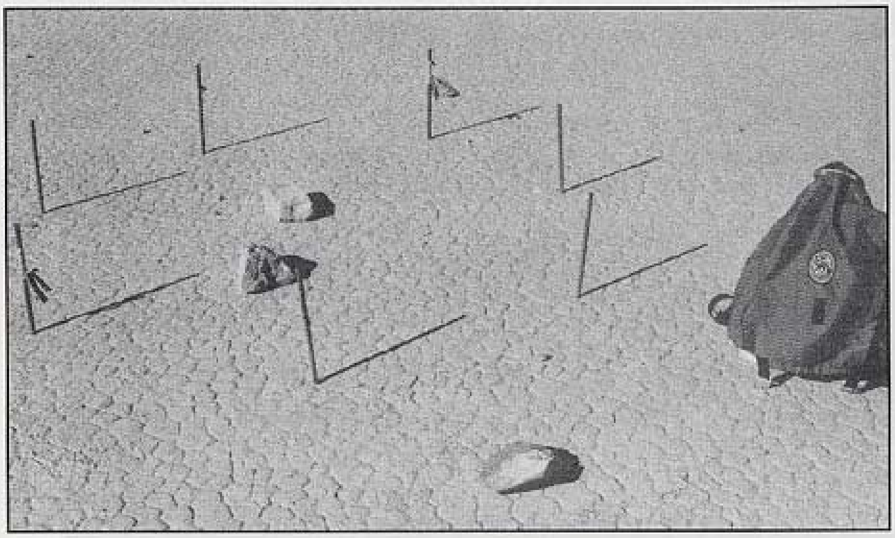


Photo 4. Bob Sharp's "corral," which tested the ice floe hypothesis. One rock left a trail as it slid out of the corral, leaving two behind. If rocks move only when embedded in ice sheets, such a phenomenon would be difficult to explain. *Photo by Bob Sharp. Taken from Sharp and Carey (1976).*

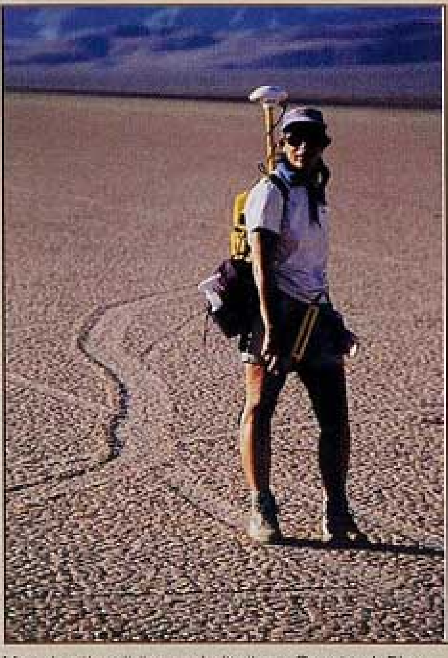
racy requirements, and to overcome some of the logistical obstacles in this inhospitable environment. Further computer processing of the field data, a technique called Differential GPS (DGPS), enabled us to produce a digital map, accurate to less than 1 m (sub-meter accuracy). (Since the trail headings record wind directions, and parallelism of trails may provide evidence for the work of ice sheets, sub-meter accuracy was desirable.) We also developed an extensive digital database that contains a variety of attributes about each rock, trail and their environs. Besides its obvious value in our study, this data set can be easily used as a basis for future studies. Our sub-meter accuracy, georeferenced map will also provide any future monitoring efforts a basis for comparison.

est) rocks produce the shortest trails, nor did the smallest (lightest) rocks produce the longest trails. Sharp and Carey (1976) reported that rounded rocks produced the most sinuous trails, while blocky fragments had a tendency to move along straighter paths. While the number of rocks surveyed in these earlier studies was limited by the demanding conditions and laborious processes associated with field survey techniques, the reasons for selecting those particular rocks were never reported; hence, one must question whether the samples were representative of the entire rock population.

In 1996, we surveyed the entire network of trails and their associated rocks as a critical step in solving the mystery of the sliding rocks of Racetrack Playa. This was made feasible with the advent of a new cartographic tool that uses the Global Positioning System (GPS). With this system, one person, carrying a hand-held GPS receiver and associated equipment, is capable of obtaining coordinates (latitude and longitude) for any surface feature. The non-impact nature of GPS mapping made it the only choice to satisfy mapping accu-

GPS Mapping—High Tech Solution

The Global Positioning System (GPS) is a constellation of 24 active satellites, and was originally designed in the 1970s as a navigation system for joint-service U.S. military applications. It reached full operational capability in April 1995 and has since become an integral global utility for positioning, navigation and timing for use in a broad range of civilian, commercial, and scientific interests, both in the U.S. and internationally. These GPS satellites transmit specially coded radio signals that are processed in a ground-based GPS receiver to compute position, velocity and time. Prior to May 2000, stand-alone civilian GPS receivers calculated positions to within 100 m of true location; however, rapid development of portable, commercially-available civilian receivers were capable of eliminating much of this error and achieving sub-meter accuracy using a correction technique. Generally this correction technique simultaneously compares satellite signals at unknown locations with those at known base stations. This signal difference or differential is used as a correction factor to eliminate the largest part of the 100-meter error that civilian users faced—this technique is called Differential GPS (DGPS). This error was actually an intentional degradation of the satellite signals by the U.S. military, called Selective Availability (SA), and was discontinued at Midnight, Eastern Daylight Time on May 1, 2000; now, GPS positions are within 10 to 22 m of true without applying the differential correction (Shaw and others, 2000).



Mapping the sliding rocks/trails on Racetrack Playa relied on Global Positioning System receivers and related equipment. Paula Messina as seen here sports the receiver and logger used in our field work. *Photo by Phil Stoffer.*

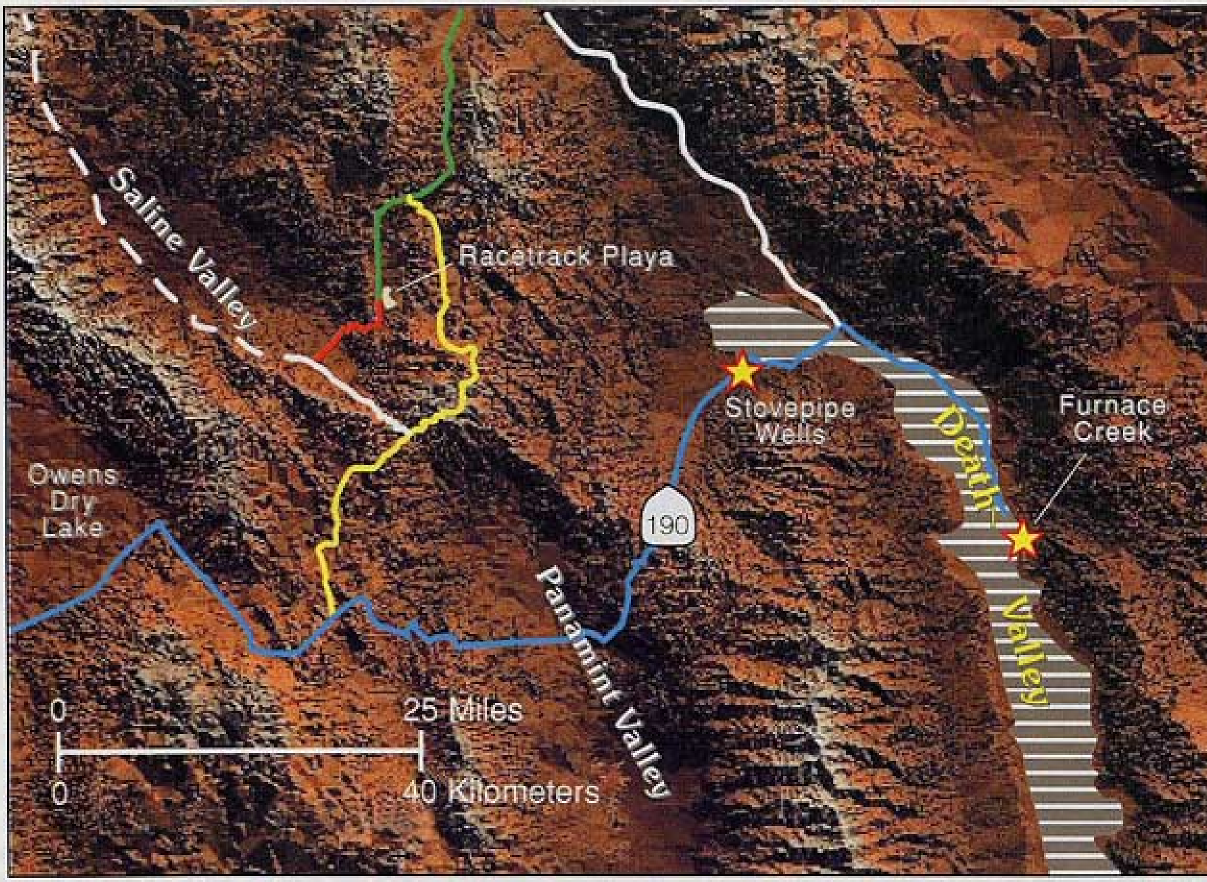


Figure 3. Shaded relief map of the region around Racetrack Playa. Unpaved access roads include the Racetrack Road (green), which is accessible from the north near Scotty's Castle; Lippincott Road (red), which is accessible by 4-wheel drive through Saline Valley; and Hunter Mountain Road (yellow), also 4-wheel drive, which connects with state highway 190 to the southwest (blue).

DEATH VALLEY SUMMER FIELD WORK—but it's a dry heat...

Death Valley is aptly named. For many, field work here during the summer months is usually avoided; however, because of previous personal commitments, our 8-day mapping mission began during the hottest time of the season—July 16, 1996. And because of the high, daytime temperatures, we chose to begin our surveys at 3:00 am. We commuted to Racetrack every day from Stovepipe Wells on one of three unpaved roads that provide the only access to the Racetrack (Figure 3). We took the most-traveled route that enters the Racetrack Basin from the north; it is carved into an alluvial fan, rich in its density of sharp, upward-pointing rocks. (Since our first visit in 1993, we unwillingly sacrificed 13 tires to the Racetrack's roads.) A welcome intersection, Teakettle Junction, marks the point where only six of the 28 miles of rough road remain (Photo 5). The road from the south, over Hunter Mountain, is usually passable in warmer months but subject to rocks slides (Photo 6) and other hazards. The Lippincott Mine Road, which leads from Saline Valley to the Racetrack Basin, is probably best traversed by helicopter (Photo 7).

Of all vital field supplies, the one limiting necessity was power. With two VCR batteries connected, the GPS receiver could collect data points for up to 8 hours: a typical day of field work. In the evening it was necessary to recharge the power sources. While it was possible to rejuvenate the batteries using the cigarette lighter adapter (thus saving us 4-to-6 hours in total round-trip travel time per day), the chance of draining our vehicle's battery, thus stranding ourselves in one of the most remote areas in the U.S. provided enough impetus to persevere the dreaded roads, every day...twice a day! By staying in an air-conditioned motel (and bar) in Stovepipe Wells, we were able to satisfy our own "power requirements," as well.

COLLECTING THE DATA

One surveyor, using GPS, can accomplish in one day what would have taken weeks using traditional survey equipment. Satellite signals are continuously received by the GPS receiver. The receiver uses these signals to calculate its own ground location (actually the receiver's antenna) into map coordinates (latitude/longitude). As the surveyor carries the receiver to various features, their coordinates are logged—any related characteristics and labels are recorded by the surveyor (called attributes). The GPS receiver, in this case, acts like a digitizing tablet. At Racetrack Playa, one of us working as surveyor walked the playa's 12-kilometer (km) boundary, collecting latitude/longitude pairs, or points, every 10 seconds eventually describing the boundary as a digital polygon of 543 points. Other surface features, the most important being the "sliding rocks" and their trails, were also logged (these included the Grandstand and two other rock "islands," water seeps, and vegetation mounds).

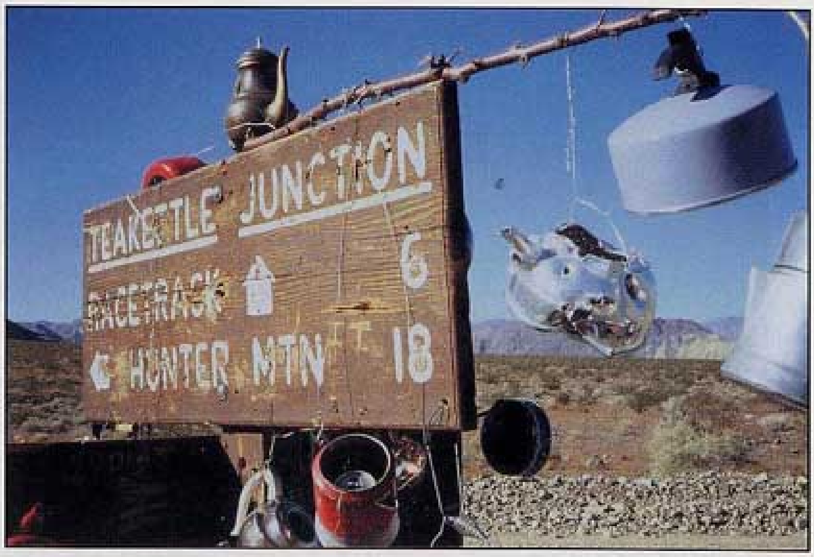


Photo 5. Teakettle Junction is the intersection between the Racetrack Road (from the north) and the Hunter Mountain Road (from the east and south). The reflective "decorations" are sometimes so numerous that the intersection can be seen from many miles away. *Photo by Paula Messina.*

Photo 6. Fallen rock zone on the Hunter Mountain Road, June 2000. *Photo by Paula Messina.*

When collecting a point location, at least ten coordinate pairs were logged by the GPS unit (one point per second for at least ten seconds). For each point, these coordinates were later spatially averaged as part of our DGPS, post-processing technique to improve accuracy. Rocks were consecutively numbered and assigned female names for consistency with a prior survey (Sharp and Carey, 1976). The rocks' physical attributes (i.e., rock height, horizontal major- and orthogonal-axes, etc.) were recorded both in a field notebook and electronically, as part of the GPS data set. All rocks were photographed with a digital camera for easier identification in future monitoring surveys.

Photo 7. The Lippincott Road connects Racetrack Basin to Saline Valley. *Photo by Paula Messina.*

Sliding rock trails were logged as line features in the direction of inferred inscription (i.e., with the rock's location as the endpoint) with a point collected every 2 seconds as the surveyor walked at a steady pace. Important points along these trails, such as abrupt changes in direction or temporary resting places (coined "sitz marks" by Sharp and Carey, 1976) were logged carefully, sometimes resulting in decreased point-to-point distances within the line feature. All told, two field mappers walked about 100 km during the course of the project. These 'raw' data are further computer processed and corrected to an accuracy of ±30 cm. This process (DGPS) compared the unknown playa coordinates with coordinates of a known, or reference, base station in Sacramento. Data were input to a Geographic Information System (GIS) computer mapping environment (ArcView version 3.0) and a database containing 50 different attributes for each of the rocks and trails used in our analyses (a total of 132 rock/trail pairs). Hence, the first complete, sub-meter map of all sliding rock trails was generated by only two field surveyors in under 2 weeks (Figure 4). Many of our numeric correlations were tested using spreadsheet computer software (Microsoft Excel for Windows 95).

The resulting map shows a tangled network of trails, with rocks scattered rather evenly within an area previously misnamed the "boulder field" (83% of the rocks are within the clast-size range of cobbles, classified as 6.4 - 25.6 cm; boulders are greater than 25.6 cm). Although 162 rocks and/or trails were logged, 30 of these were omitted for the following reasons. Twenty were excluded because their lithology was exotic (undifferentiated intrusives) to the playa and the area (we think they were intentionally placed on the playa) unlike the majority (92%) of playa rocks that are dolomitic. Clearly most of the playa rocks originate from one of the two abutting dolomite cliffs at the Racetrack's south end, with the exception of some igneous fragments, which may be tumbling down from Ubehebe Peak to the west. (However, a deep ditch excavated by the National Park Service in 1969 to prevent off-road vehicles from entering onto the playa has cut off the rock supply from this western Ubehebe Peak talus slope.) Seven trails were omitted, since they had rocks at both ends, or at neither. Without knowing the origin and end points, it was impossible to infer a trail's true heading; Kirk (1952), and Sharp and Carey (1976) reported similar features, and ascribed them to the work of vandals. Two trails were omitted due to undetermined technical problems during data collection and one trail was counted twice due to surveyor error.

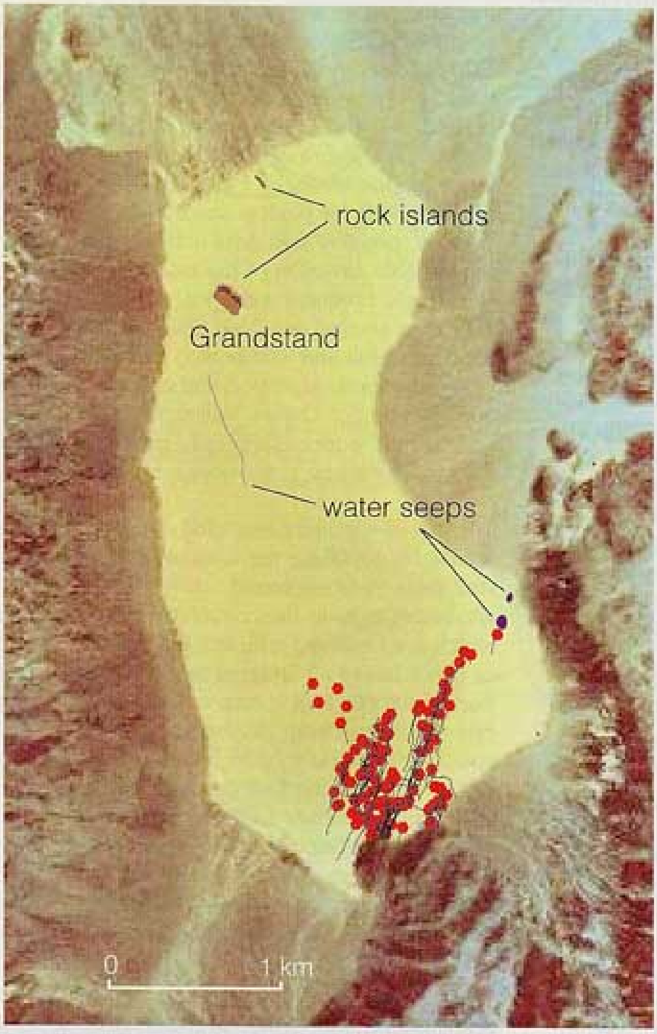


Figure 4. Sliding rock trails of (black lines) Racetrack Playa, Death Valley National Park, California. This also shows 132 corresponding "sliding" rocks (red circles). Rock 'islands' and springs or water seeps are labeled. These features were surveyed using GPS in 1996 by the authors. *Cartography and GIS integration by Paula Messina. Base map is USGS aerial photograph.*

REDUCED TO NUMBERS

Of the "sliding" rocks observed in 1996 on the Racetrack Playa, the average rock was a medium-sized cobble (about 20 cm), with 4.03 corners/0.36 concavities (in the "footprint" plane), and an aspect ratio of 1:1.54 (one-half again longer than its width). The length of trails ranged from 1.6 ("Mary Ann") to 880.7 m ("Diane"), which is far longer than any previous survey had reported. Mean trail length was 211.7 m. The straightness of a trail was calculated by dividing the total trail length into the straight-line distance (length of line connecting the start- and end-points)—the more convoluted the trail the lower the resulting value. The most convoluted trails in our study were found to have straightness values as low as 0.19 ("Claudia"), while only one 6-m trail approached a straight line (1.00, "Agnes"). Mean straightness ratio was found to be 0.85.

OUT OF THE FRYING PAN...crunching numbers

With the field part of our project complete, we analyzed the resulting data. If we could discern correlations among our data, then deducing a mechanism for the sliding rocks may follow. As it turned out, the statistical analyses were perhaps as grueling as the field experience. To test the many variables and their possible relation we had to construct hundreds of scatter plots (graphs), which would show graphically whether logical physical relation (i.e., rock weight vs. trail length) were related to trail characteristics. Among relationships tested, we examined if trail lengths might be affected by the height of rocks. We did this because we knew that at nearby Owens Dry Lake high wind speeds extended to within 4 cm of the ground (Bacon, Cahill and Tombrello, 1996); therefore the larger (thus generally taller) rocks might be subjected to greater horizontal forces that would, in turn, affect the trails (length or pattern) they make. Yet this proved negative. With each new plot we became more disappointed and after a while it appeared that there seemed to be no link between a rock's physical attributes and the characteristics of the trail it produced. However, after hours of further analyses another explanation soon emerged.

Our analyses that showed the greatest promise were those that compared trail characteristics to their geographic regions on the playa. The longest and straightest trails were found in higher concentrations on the eastern margin of the Racetrack, while the more convoluted, or wandering, trails were found near the playa's center. This implied that rocks were subjected to highly variable conditions depending on where they were on the playa. And because our assumption is that the main driving force was wind-caused, this may indicate that wind activity was erratic over the playa– creating microclimates. Indeed, when a survey of instantaneous wind velocities was conducted using hand held anemometers at a fixed height (1 m) along a transect across the Racetrack, as much as a six-fold variation in wind speed and a 50-degree direction differential were recorded in two locations merely 600 m apart (Messina, 1998). Similar erratic wind activity was described by Kirk (1952).

Another assumed factor in rock activity is water and/or ice. Close to the longest trails we found three seeps, formerly called "man-made water holes" (Shelton, 1953) or "sink holes" (Creutz, 1962). During most of our visits, these springs, or seeps, were filled or flowing and may indicate that the eastern margin of the Racetrack is more frequently wet from a shallow water table, thus preferentially promoting rock-sliding conditions.

WIND PATTERNS

Racetrack Playa lies downwind of two natural wind tunnels. The playa's enclosed basin configuration directs air from the southwest and, to a lesser extent, the southeast (Figure 5). Prevailing wind patterns channel air up from neighboring Saline Valley, which is over 500 m lower in elevation than Racetrack. It is possible that as the air flows up and over the southeast rim of Saline Valley it is compressed causing turbulence around Ubehebe Peak. This may account both for peak gusts of high velocity, possibly dust-devil activity, and the variable direction of the tracks in Racetrack. Frequent wind gusts up to 40 m per second occur on Owens Lake (Bacon, Cahill and Tombrello, 1996). Given the lower elevation and open configuration of Owens Valley, wind speeds on the topographically-confined Racetrack may be even more intense.

Stronger straight-line winds may be focused onto where the longest, and straighter trails are found, while erratic winds can explain the convoluted trails, which are clustered near the intersection of two inferred air streams in the central part of the playa. It is interesting that one trail shows both clockwise and counter-clockwise motion (Figure 6)– this may reflect the fact that dust devils may rotate in either direction with similar frequency (Snow and McClelland, 1990). Experimental data show that the pressure changes in a whirlwind may be as great as 4 millibars (Greeley and Iversen, 1985), which is capable of lifting some objects. Furthermore, these simulated whirlwinds can simultaneously entrain a broad spectrum of particles, without regard for size, density or shape (Greeley and Iversen, 1985). This is unlike straight winds, which serve as excellent sorting agents. In this regard, rotating winds may act somewhat like ice sheets. At Racetrack Playa, the configuration on the lee side of the Grandstand may provide the right condition for wind-current eddies to form in the central part of the playa.

TANDEM TRAILS— CONVERGING TRAILS

Another way to evaluate the "sliding"rocks of Racetrack Playa is to compare the pattern of adjacent trails. Parallel or congruent trails have been suggested to indicate ice rafting. In this scenario rocks must be embedded in a single sheet of ice when they move (Stanley, 1955 and Reid and others, 1995), thereby maintaining a constant distance between them. While the problem with this interpretation is that while earlier surveys show parallelism near their origins, in many cases the trails diverge. This pattern may be explained as the eventual fracture of a once-continuous ice sheet (Figure 2).

Our mapping, however, shows interesting trail patterns that contradict ice rafting. Figure 7 shows two trails with strangely contorted end-signatures. While the trails show a great deal of

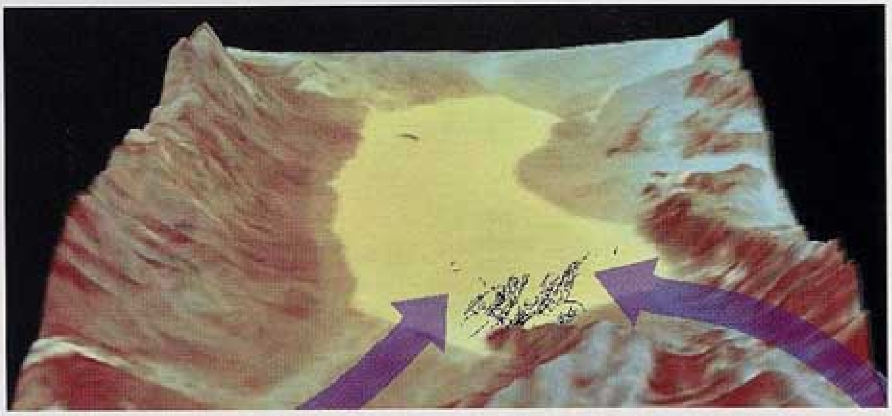


Figure 5. Looking north. Oblique computer-generated view of the Racetrack Playa's topography. Arrows show direction of wind tunneling into the southern part of the Playa. This image uses a USGS aerial photograph draped over the Ubehebe Peak digital elevation model. The sliding rock trails are also shown.

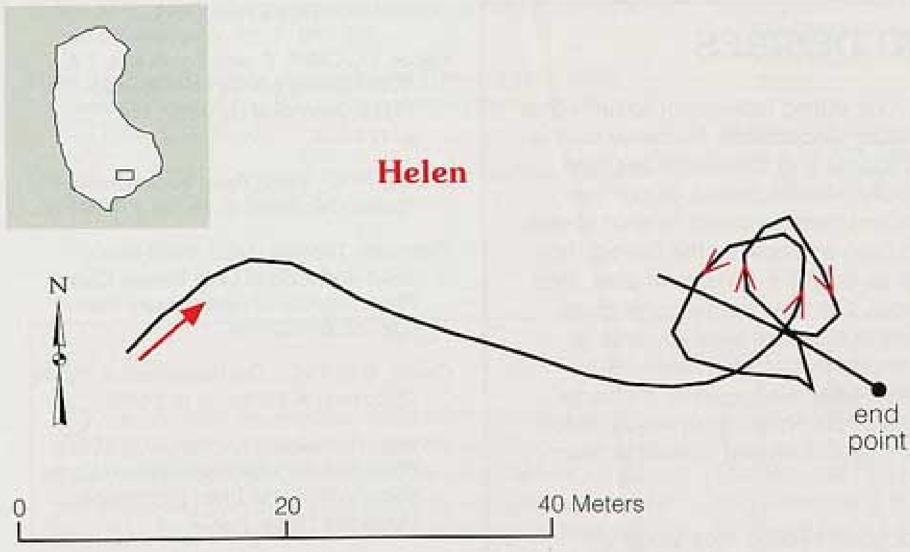


Figure 6. The trail produced by one of the 132 'sliding' rocks mapped in 1996. This rock, designated Helen, is in the south-central portion of the Racetrack Playa. The direction of movement is indicated by arrow. The motion along this trail first rotates once counter-clockwise, and then clockwise.

congruence, they continually converge upon each other. It seems implausible to describe this type of activity within the bounds of an ice floe theory, unless ice began to break apart and pile up. However, there is no indication of surface ice-gouging in the area around these rocks. If rocks are subject to nearly-identical wind patterns, they may carve nearly-identical patterns in the playa muds. While the same may be said for the ice model, the distance between two or more rocks would either remain the same, or increase, but could never decrease.

FOLLOW-UP SURVEYS

Our 1996 survey has captured a "snapshot" of an ongoing geological surface process on Racetrack Playa. Since then, follow-up surveys have been conducted building on our 1996 base map. In May 1998 Paula Messina returned to the playa to see whether the intense El Niño-related storms of the winter of 1997-98, which affected eastern California, set the rocks in motion. It was surprising that most rocks were exactly where they had been mapped in 1996. The one rock that had previously moved the farthest ("Diane") had a mere 6-m extension to the trail mapped in 1996, the most extensive change in our data set. Subsequent visits (August 1999; November 1999) revealed no changes; finally, in June 2000, two rocks new to the data set showed evidence of having traveled 45.5 m and 6.1 m, respectively. Although these rocks were likely on the playa surface in previous visits, there were no visible trails associated with them, indicating that their prior record of travel had long been erased. The relative inactivity of the sliding rocks through the 1990s is in direct contrast to movement assumed for the "one- to two-year" period through the late 1960s and early 1970s described by Sharp and Carey (1976). Why the rocks have remained so "lethargic" through El Niño dominated winters and several notable storms that affected the region is unknown. While monitoring the rocks 3 decades ago, Sharp and Carey, perplexed by the continued lack of eyewitnesses, assumed that "some immutable law of nature probably prescribes

Figure 7. The trails of Jacki and Julie, two 'sliding' rocks on the Racetrack Playa. Direction of movement is shown by arrow. This map shows many similarities between the two traces, yet they converged toward each other near their end points.

DEVICES AND DESIRES

Most who theorize on the causes of rock sliding movement assume that the high-velocity winds are at least indirectly responsible. Evidence for the high wind speeds at Racetrack Playa is sparse and somewhat qualitive, but we do know wind velocities can be quite intense, based on our own limited measurements by handheld devices (measurements of wind speeds at the Racetrack are limited to handheld devices because the Desert Protection Act of 1994 designated the playa as part of a wilderness area, thus prohibiting any permanent instrumentation). Other evidence came three decades earlier, when workers attempting to measure wind currents at Racetrack constructed a tower with a complement of wind-measuring devices. Unfortunately, the tower was soon-after destroyed by the same high-velocity winds they wanted to measure. So while air currents provide a piece of the puzzle for why the boulders slide, they are difficult to quantify and to study on a long-term basis.

Direct observation of the 'sliding' rock phenomenon may ultimately settle this debate. However, given the remoteness of the area and the extreme weather conditions that likely prevail during the most probable time of "rock sliding," it's highly unlikely anyone will witness this activity. To get around this, some researchers have proposed placing radio transmitters on the sliding rocks in an attempt to remotely monitor, or track, the rocks' "progress." The rock movements could then be possibly correlated to weather conditions. However, such a monitoring strategy would also be prohibited by the National Park policy.

that movements occur in the darkness of stormy moonless nights, so that even a resident observer would see newly made tracks only in the dawn of a new day." Since our own mapping took place in the early morning hours, under a 'veil of darkness,' it would seem this idea too might be implausible. And so we are similarly bewildered. So much so that in a moment of exasperation we ask, "Are the rocks staying put because they know they're being watched?"

THE NOT SO FINAL WORD

The Racetrack Playa may be thought of as a mosaic of microclimates, each with differing sediment inflow, saturation potential, cyanobacterial presence and wind climate. Rocks on this playa exhibit varying magnitudes and directions of movement, which may be related to the local conditions acting on them. It is not unreasonable to infer that when similar conditions act on physically dissimilar rocks, they may react in similar ways. Parallel or near-parallel trails may be inscribed this way, but the vast majority of trails show almost no parallelism with others; we think this reflects the erratic winds of the region. Furthermore, rock sliding activity may not be limited to the incidence of winter storms; summer monsoons, which are common at the playa's elevation, may promote conditions favorable to this phenomenon as well.

Studying these trails or 'fossil' tracks on Racetrack Playa is geology at its best. That is, we are attempting to explain unobserved events with only their traces as clues. And although these events are happening on a human time scale, we are still confined to methods and tools similar to those used by paleontologists studying fossils billions of years old. The only difference is that someone may just luck out some day, and be wandering the Racetrack to catch sight of what we're certain is an unparalleled spectacle (no pun intended).

REFERENCES

Bacon, D., Cahill, T. and Tombrello, T.A., 1996, Sailing stones on Racetrack Playa: Journal of Geology, 104, p. 121-125.

Bradley, H.C., 1963, Race track theories: Pacific Discovery, v. 16, no. 2, p. 24-26.

Clements, Thomas, 1952, Wind-blown rocks and trails of Little Bonnie Claire Playa: Journal of Sedimentary Petrology, 22, p. 182-186.

Creutz, E.C.,1962, The racing rocks: Pacific Discovery, v. 15, no. 6, p. 24-26.

Greeley, Ronald and Iversen, J.D., 1985, Wind as a geological process on Earth, Mars, Venus and Titan: Cambridge University Press, p. 333.

Kirk, L.G., 1952, Trails and rocks observed on a playa in Death Valley National Monument, California: Journal of Sedimentary Petrology, v. 22, p. 173-181.

McAllister, J.F., 1956, Geologic map of the Ubehebe Peak Quadrangle, California: U.S. Geological Survey, Geologic Quadrangle Map, GQ-95.

McAllister, J.F. and Agnew, A.F., 1948, Playa scrapers and furrows on Racetrack Playa, Inyo County, California [abstract]: Geological Society of America Bulletin, v. 87, p. 59.

Messina, Paula, 1998, The sliding rocks of Racetrack Playa, Death Valley National Park, California: Physical and Spatial Influences on Surface Processes. Published dissertation. Ann Arbor, Michigan: University Microfilms, Inc., p. 372.

Reid, John B., Bucklin, Edward P., Copenagle, Lily, Kidder, Jon, Pack, Sean M., Polissar, Pratigya J. and Williams, Michael L., 1995, Sliding rocks at the Racetrack, Death Valley: What makes them move?: Geological Society of America Geology, v. 23, no. 9, p. 819-822.

Schumm, Stanley A., 1956, The movement of rocks by wind: Journal of Sedimentary Petrology, v. 26, p. 284-286.

Sharp, Robert P. and Carey, Dwight L., 1976, Sliding stones, Racetrack Playa, California: Geological Society of America Bulletin, v. 87, p. 1704-1717.

Sharp, Robert P., Carey, Dwight L., Reid, John B., Jr., Polissar, Pratigya J. and Williams, Michael L., 1996, Sliding rocks at the Racetrack, Death Valley: What makes them move: comment and reply: Geological Society of America Geology, v. 24, no. 8, p. 766-767.

Sharp, W.E., 1960, The movement of playa scrapers by wind: Journal of Geology, v. 68, p. 567-572.

Shaw, Michael, Sandhoo, Kanwalijt and Turner, David, 2000, Modernization of the Global Positioning System: GPS World, v. 11, no. 9, p. 36-38.

Shelton, J.S., 1953, Can wind move rocks on Racetrack Playa?: Science, v. 117, p.438-439.

Snow, John T. and McClelland, T.M., 1990, Dust devils at White Sands Missile Range, New Mexico: temporal and spatial distributions: Journal of Geophysical Research, v. 95(D9), p. 13,707-13,721.

Stanley, G.M., 1955, Origin of playa stone tracks, Racetrack Playa, Inyo County, California: Geological Society of America Bulletin, v. 66, p. 1329-1350.

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Philip Stoffer received his B.A. and M.S. from Miami University of Ohio, his M.L.S. from the University of Denver, and Ph.D. from the City University of New York. At present he is the Librarian at the U.S. Geological Survey in Menlo Park, and conducts education outreach activities for San Francisco Bay area science teachers. His past field research projects have included the Late Cretaceous geology of Badlands National Park in South Dakota, and coastal processes and paleontology of the New York City region. He has previously worked in oil and gas exploration, and served as librarian at the University of Kentucky, Brooklyn College, and Lafayette High School in Brooklyn, NY.

DMG RELEASES...

OPEN-FILE REPORT 2000-19. A GENERAL LOCATION GUIDE FOR ULTRAMAFIC ROCKS IN CALIFORNIA—AREAS MORE LIKELY TO CONTAIN NATURALLY OCCURRING ASBESTOS. By Ronald K. Churchill and Robert L. Hill. 1 plate, map scale 1:1,000,000. $20.00.

Natural asbestos commonly occurs in association with altered ultramafic rocks, including serpentinite. Therefore, a map showing ultramafic rock areas can be used as a general guide to places that are more likely to contain naturally occurring asbestos. The small scale of this map (1:1,000,000) precludes showing detailed boundaries of the ultramafic rock units and small occurrences of ultramafic rock.

OFR 2000-19 is available for reference at DMG's Sacramento, San Francisco and Los Angeles offices. It can be purchased: 1) by phone using VISA, MasterCard or American Express; 2) by mail with check or money order; or 3) over-the-counter at the Sacramento office. DMG offices are listed on the masthead.

Surveying The Latest Pictures From Mars

Malin Space Science Systems
P.O. Box 910148
San Diego, CA 92191-0148

Pictures from the Mars Orbiter Camera (MOC) aboard the Mars Global Surveyor (MGS) spacecraft are revolutionizing our understanding of the geology and geomorphology of Earth's neighboring world. Many MOC images show features at scales similar to aerial photographs used in terrestrial field work, and many of these pictures show landforms like those found in California. The pictures provide tantalizing glimpses that reveal Mars to be a dynamic world in which evidence for ancient geologic change has been recorded in layered rock and volcanic flows; and modern geomorphic processes are seen in the form of dust storms, dust avalanches, and changing patterns of frost in the polar regions of the red planet.

The Mars Orbiter Camera, proposed to NASA in 1985, was first flown on the Mars Observer spacecraft that was lost 3 days before reaching the planet in August 1993. Following that loss, the MOC was selected again for its new spacecraft, Mars Global Surveyor, launched in November 1996. MGS began orbiting Mars in September 1997, but its Primary Mission—to examine the planet for 1 Martian year—did not begin until the spacecraft was in a circular, polar orbit about 380 kilometers (km) above the surface in March 1999. The Primary Mission ends in February 2001, with an Extended Mission phase slated to run into April 2002.

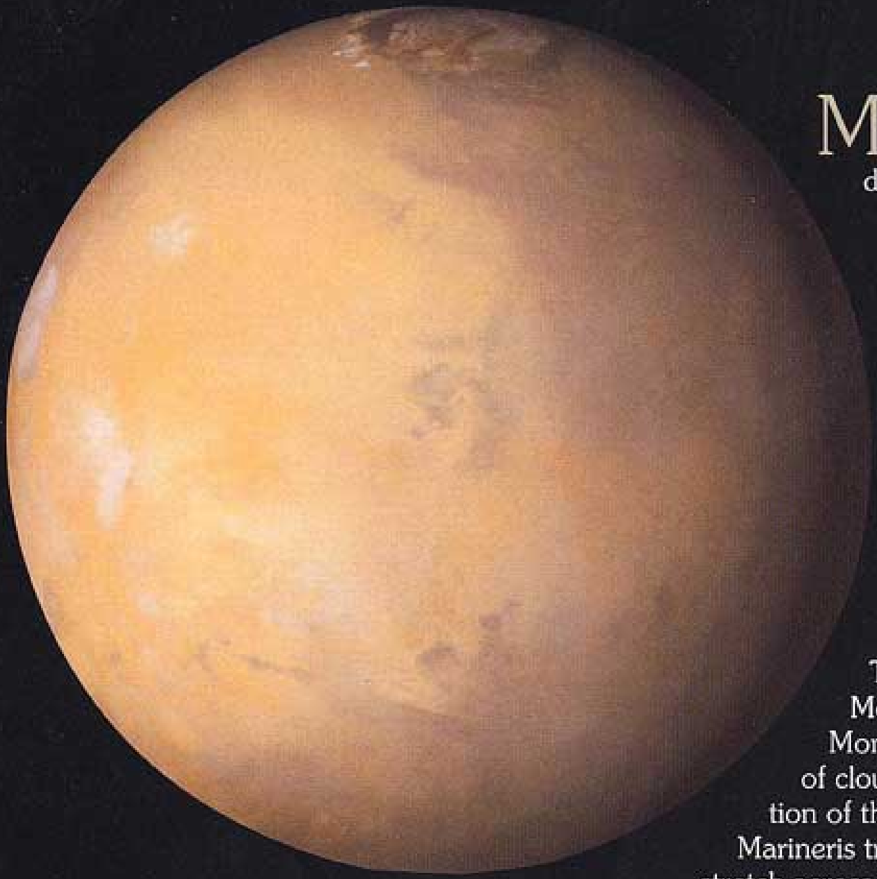
The MOC consists of three cameras in one: a panchromatic narrow angle camera that acquires high-resolution views (1.5 to 12.0 meters/pixel*), and 2 red and blue wide angle cameras to provide context for the narrow angle images (at 240 meters/pixel). These cameras obtain regional views of the planet (typically at 240 to 960 meters/pixel), and supply daily global maps for weather and frost monitoring (at 7.5 km/pixel). The MOC is operated by a team of seven people at Malin Space Science Systems in San Diego, California, through a contract with California Institute of Technology's (Caltech's) Jet Propulsion Laboratory, which manages the MGS mission for NASA.

Selecting pictures to be taken by MOC requires a human—usually one of the two authors—to sit at a computer terminal and examine the latest predicted orbits that MGS will follow. These predictions are based on a photomosaic map made from pictures obtained by the Viking orbiters of the 1970s. At the end of the year 2000, more than 80,000 pictures had been acquired by MOC. On the pages that follow, we present a sampling of some of our favorite images that illustrate a range of geologic and geomorphic features on Mars. Tens of thousands of archived MOC images and hundreds of captioned media releases are available over the Internet at http://www.msss.com/.

*Pixel is an acronym from picture element; it is the smallest element (a dot) on a display screen.

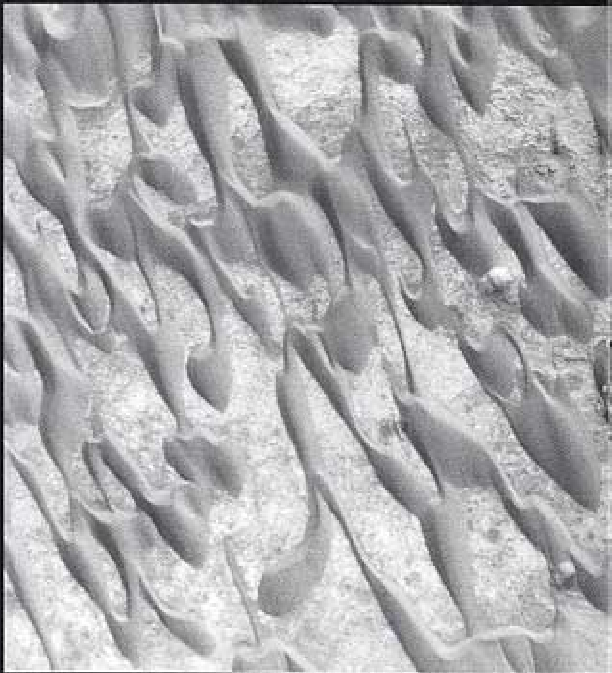
California and Mars—A sense of scale. MOC images are very much like aerial photographs. Shown at the same scale, the picture below is a portion of an air photo of the Bristol Mountain Range approximately 12 km due north of the Amboy lava field in the Mojave Desert, California; the picture on the right is a portion of the central peak of Hale Crater at 35.7°S, 36.5°W on Mars. Each picture covers an area 2.9 by 2.4 km. In both images, gullies interpreted to have been carved by running water are seen (Malin and Edgett, 2000). The dark, almost fuzzy-looking features at the center of the Mars picture are sand dunes.

The Bristol Mountains photo (left) is courtesy of the U.S. Geological Survey, the Mars picture is a subframe of MOC image M09-04718. Both pictures are illuminated from the upper left; to obtain this illumination, the Bristol Mountain picture was rotated so north is toward the bottom. In this and other Mars pictures presented here, except where noted, north is toward the top.

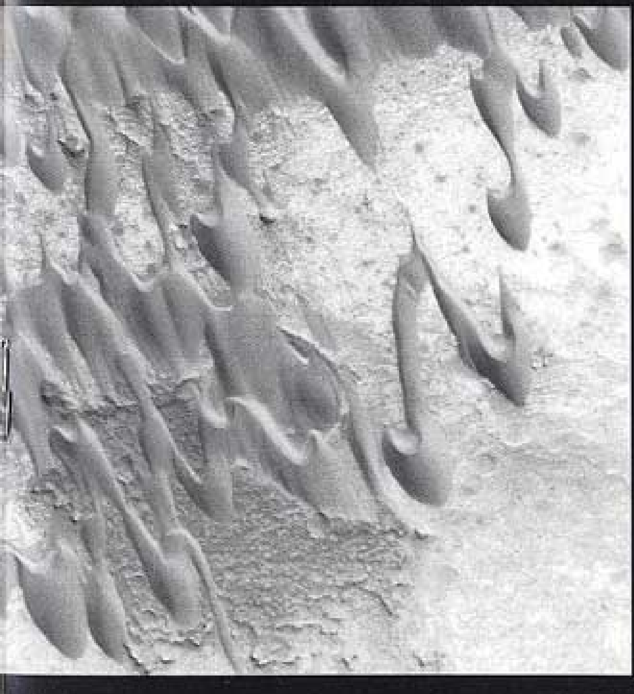


WIND AND WEATHER

Mapping Martian weather. This picture is a color composite of 9 red and 9 blue daily global images mosaiced, or pieced, together and digitally wrapped around a sphere to show part of the western hemisphere of Mars during northern summer as it appeared to the MGS MOC in March 1999. The north polar ice cap is visible at the top. On Mars, clouds often form each afternoon around high mountains: at the far left, a white patchy cloud denotes the location of an Arizona-sized volcano, Olympus Mons. Ascraeus Mons (another larger volcano) is under the brightest cloud toward the center left. The volcanoes Pavonis Mons and Arsia Mons (toward lower left below Ascraeus Mons) have much less cloud cover. The patch of clouds toward the upper left mark the location of the Alba Patera volcano. The Valles Marineris trough system—so long that it would stretch across North America—is seen in the lower third of this picture. Mars has a diameter about half that of Earth—the average is about 6,780 km. The color in this and other pictures presented here has been computer-enhanced and is not shown as it would actually appear to the human eye. The colors would indeed appear more washed-out and bland if seen by a human looking down on the planet from space.

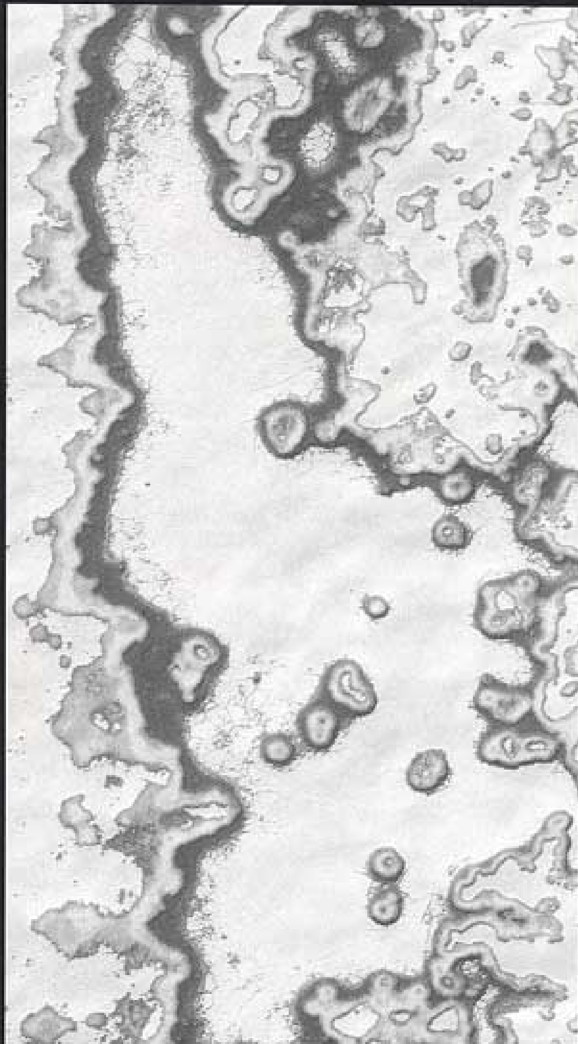


Geologic action–dust storms (2 photos at right). The thermal contrast between the cold Martian north polar cap (top, right) and the sandy/rocky northern plains (top, left) gives rise to winds powerful enough to raise dust into a large plume as shown here. A similar situation occurs between the thermal contrast of the Sahara Desert and Atlantic Ocean off the northwest coast of Africa (lower right). The Martian storm, centered near 63°N, 42°W, is moving as a front extending southward (toward left) about 900 km from the edge of the north polar frost cap. The Martian storm was observed by MOC late on August 29, 2000. The terrestrial storm was viewed by the SeaWiFS instrument aboard the SeaStar satellite on February 26, 2000; this storm extends about 1800 km westward from the African coast. The two pictures are shown at the same scale. The SeaWiFS picture appears courtesy of NASA's Goddard Space Flight Center and ORBIMAGE/ SeaWiFS Project. The MOC image is a composite of red and blue wide angle subframes of M18-01828 and M18-01829.

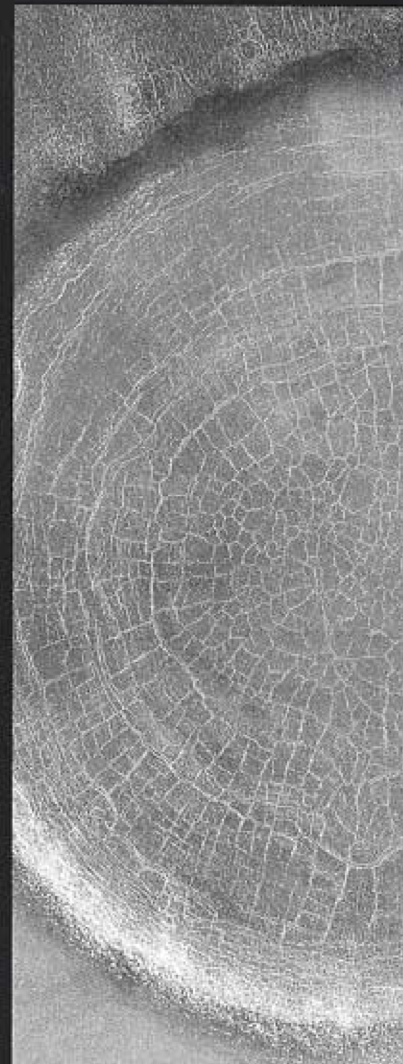


Sand dunes in the Nili Patera caldera. Martian winds move sand as well as dust. The MOC narrow angle camera captured this view of a barchan* dune field on the floor of the caldera of the low, broad shield volcano, Nili Patera. The steeply sloping dune slip faces indicate that the sand is traveling from the lower right toward upper left. Thermal Emission Spectrometer observations from MGS show that these dunes and the rocky substrate across which they are traveling are basaltic (Bandfield and others, 2000). Sunlight illuminates the scene, which covers an area 3.0 by 5.7 km, from the right. North is to the right. Subframe of MOC image FHA-00451, near 8.9°N, 292.6°W.

*Barchan dunes are crescent-shaped dunes with a gently sloping convex side facing the wind. The steeply sloping concave side face down-wind.



South polar cap in summer—narrow angle view. MOC's high resolution images of the Martian south polar cap present one of the biggest unsolved mysteries of the MGS mission—why does some of its surface look like stacked and broken slices of swiss cheese? The south polar cap is layered; the upper layers are 2 to 4 m thick and have features that may result from collapse of the subsurface (such as karst topography that forms in areas underlain with limestone) as well as enigmatic circular and semi-circular "swiss cheese" holes (Thomas and others, 2000). This picture, covering an area 3.0 by 5.7 km, shows what the polar cap looked like in summer (April 2000) when much of the bright seasonal frost had sublimed away (vaporizes). Some exposed layers appear dark while others are bright, suggesting that different layers of the polar cap have different thermal properties so that some retain frost long into summer, while others do not. Polygonal cracks are evident in some of the layers. No one yet knows quite what to make of these observations. Illuminated from the upper left, subframe of image M14-01694, near 86.7°S, 107.9°W.

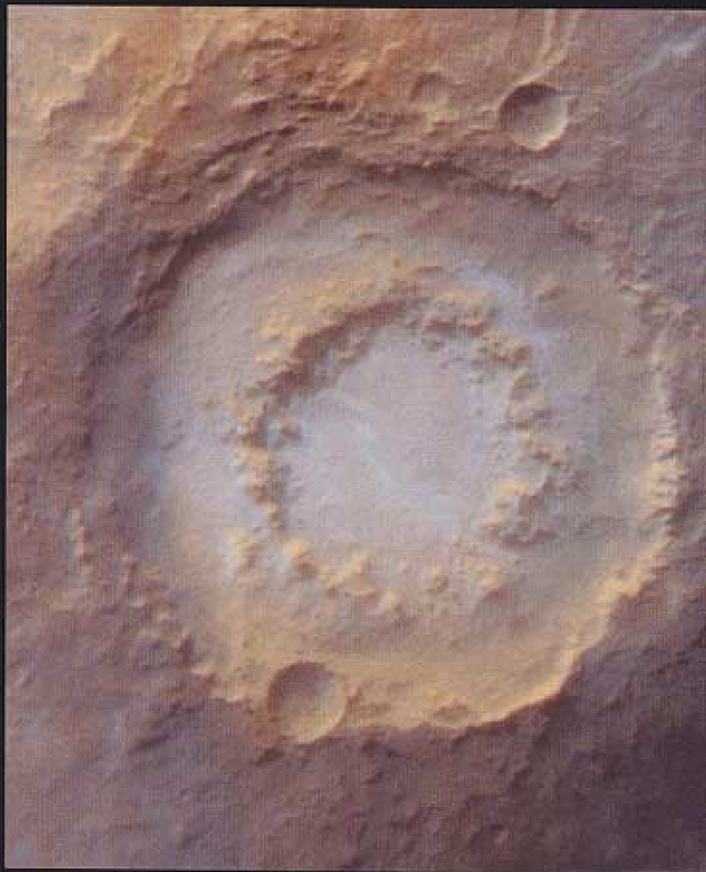


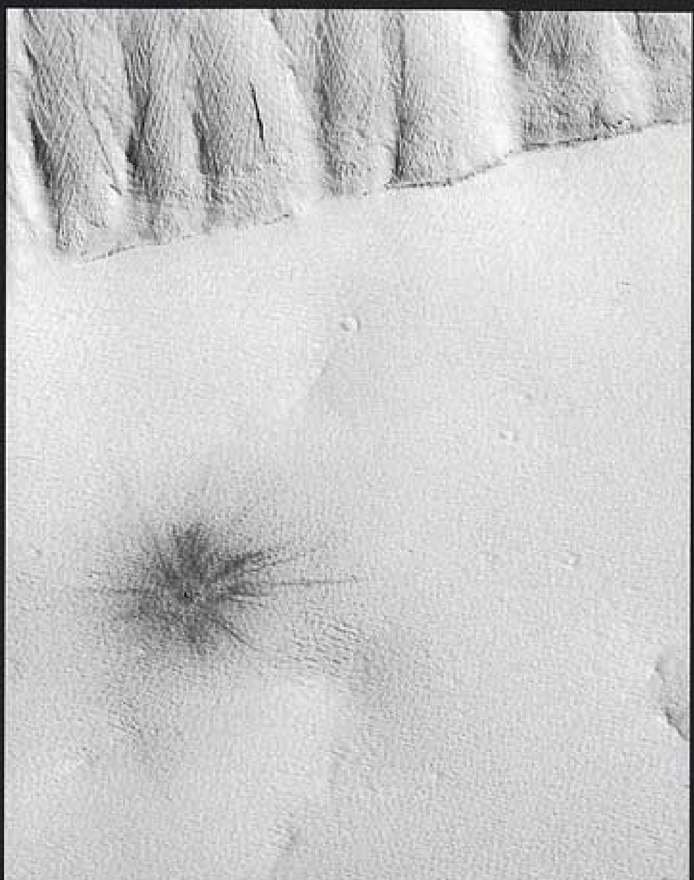
Polygons at high latitude—indicators of ground ice? Frost trapped in cracks highlights polygonal patterns on the floor of an ancient meteor crater on the Martian northern plains near 65.6°N, 327.6°W. Frost on the crater rim can be seen arcing across the lower left/center of the scene, which despite appearances, is actually illuminated by sunlight from the lower left. Polygons such as these are common in the Martian polar and sub-polar regions and are believed to be indicators of periglacial* processes. Subframe of MOC image M19-00047, covering an area roughly 3.0 by 7.9 km.

*Periglacial processes occur at the immediate margins of glaciers and ice sheets and thus are influenced by the cold temperatures.

IMPACT CRATERS

Autumn frost in Lowell Crater. All bodies in our solar system have been subjected to the occasional impact of meteors, asteroids, and comets. Mars has been no exception. MOC captured this view of autumn frosts in Lowell Crater in mid-October 2000. This crater is named after Percival Lowell, the late 19th-early 20th-century astronomer who promoted Mars as an abode of intelligent life. This approximately 200 km-wide crater is an example of one of the larger ones on the red planet. Composite of MOC red/blue wide angle images M20-01002 and M20-01003.



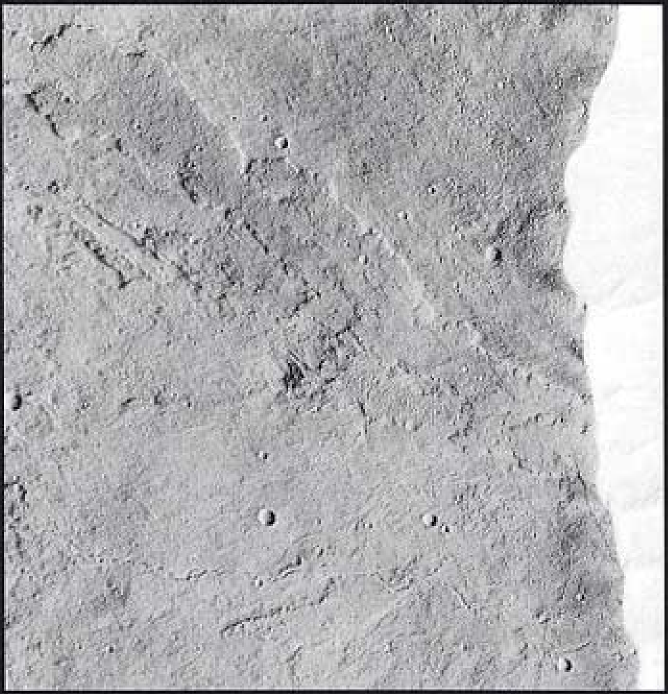


A small, fresh meteor crater on Ulysses Patera. Martian craters come in all sizes, from those that are over 1000 km across, to those of a few hundred km like Lowell (above), to some that are very tiny, like that shown at left. The crater surrounded by rays of dark ejecta at the center-left of this scene is only about 30 m in diameter. Very few small craters on Mars exhibit this pattern, suggesting that this one formed so recently that there has been little time for wind to erode it or for dust to obscure the finely-detailed ejecta. When the crater may have formed is unknown, but the preservation of its ejecta suggests that it may be only a few years to a few decades old, at most. The crater occurs near the summit of the volcano, Ulysses Patera. The upper portions of the southeastern wall of this volcano's caldera is seen at the top of the picture. This image is illuminated from the left and covers an area 3.0 by 4.2 km. Sub-frame of MOC image M08-01170, near 2.4°N, 121.2°W.

VOLCANIC FEATURES

Olympus Mons volcano. The MOC wide angle cameras obtained this east-looking oblique view of Olympus Mons, the largest volcano on Mars, in April 1998. Olympus is a shield that stands more than 3 times higher (relative to the surrounding terrain) than the summit of Mt. Everest (relative to sea level). The entire Hawaiian Island chain would stretch across the diameter of this Martian shield; the entire state of Arizona would be covered by this massive landform. The arrow points to the western edge of the summit caldera complex, and indicates the location of the lava flow in the next photo. Illuminated from the upper right, this is a composite of MOC images SP1- 26301 and SP1-26302.

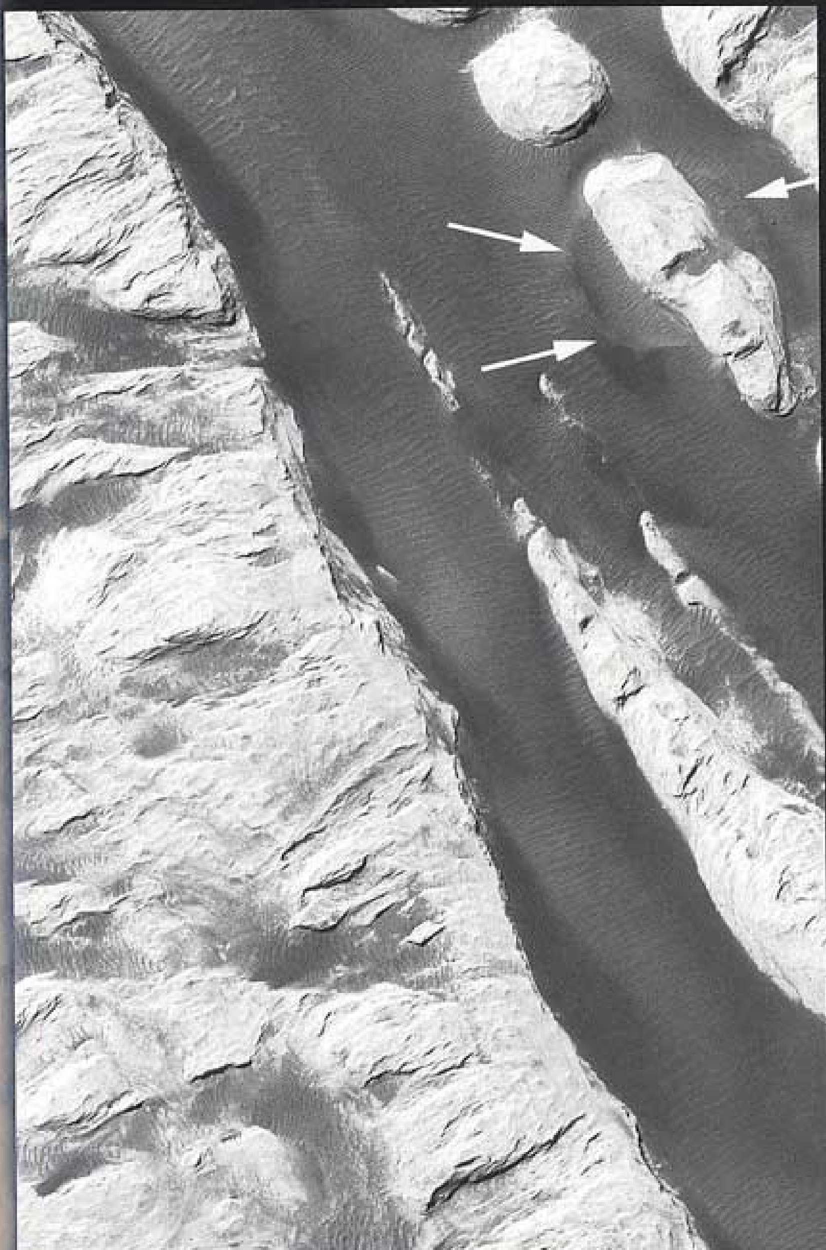
Lava flow at Olympus Mons summit. The arrow in the previous photo shows the location of this MOC narrow angle view, illuminated from the right, at the top of Olympus Mons. The upper west wall of a caldera at the volcano summit is seen at the right. A lava flow, truncated by the caldera collapse at center-right, runs diagonally toward the upper left. Small impact craters formed by meteors dot the scene. This picture covers an area 7.9 by 8.0 km near 18.5°N, 134.0°W. Subframe of MOC image SP2-35605.



Small volcano in the Martian region called Tempe Terra. Not all Martian volcanoes are monstrously huge. This one near 36.2°N, 85.1°W, is one of many small volcanoes on Mars and is similar in both shape and size to many of the small basalt shields found, for example, on the Snake River Plain in Idaho (Hodges and Moore, 1994, Figures 13C, D). The elliptical feature is the summit caldera of a low, elongate volcano mound. The volcano, however, does not show many of the features generally found around similarly sized volcanoes on Earth. Instead of the lava flows and leveed channels, only a faint pattern of subtle, somewhat sinuous ridges and troughs radiate out from the elliptical caldera. This pattern gives the surface of the volcano and its surroundings quite a rough appearance. Much of this "sandpaper-like" texture appears to be unrelated to the volcano, but is instead an expression of the eroded regolith that covers the old flows. The circular feature nearly superposing the rim of the caldera is an impact crater. The troughs in the lower portions of the image are grabens with rippled dunes on their floors. The caldera is approximately 150 m deep and 2 km long. Illuminated from the left, subframe of image SP2-50704.

STRATIGRAPHIC MARS

A history recorded in layers. It may seem surprising now, but before the MGS reached Mars in 1997, most planetary geologists thought that except where layers of lava flows are present, the upper few kilometers of the Martian crust would consist mainly of jumbled and fractured rocks, the result of billions of years of asteroid and comet impacts. Such seems to be case, for example, in the cratered highlands of the Moon. However, the earliest pictures taken by MOC of the walls of the Valles Marineris—a system of tectonic and mass-wasted troughs and chasms so vast they would stretch from Los Angeles to New York—showed layered rock extending to depths as much as 10 km beneath the Martian surface (Malin and others 1998; McEwen and others, 1999). This observation was the first of many that would shake the foundations of Martian geology as it was understood before MGS arrived. This picture shows layers in the upper walls of a mesa in Coprates Chasma—one of the Valles Marineris troughs. Arrows indicate the location of faults bounding a graben (faulted valley) that offsets some of the layers in this mesa. The presence of layered rock indicates that Mars has a record that is amenable to traditional geologic field work—ah, if we could only go there. Illuminated from the left, subframe of MOC image AB1-08003 "colorized" using red, green, and violet filter images acquired 2 decades earlier by the Viking orbiters. It covers an area approximately 10 by 8.5 km near 14.6°S, 55.8°W.

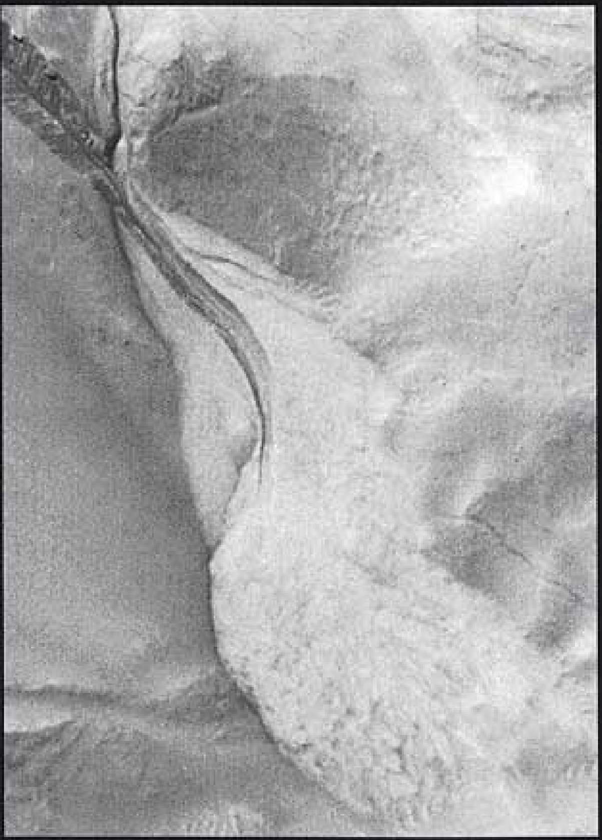


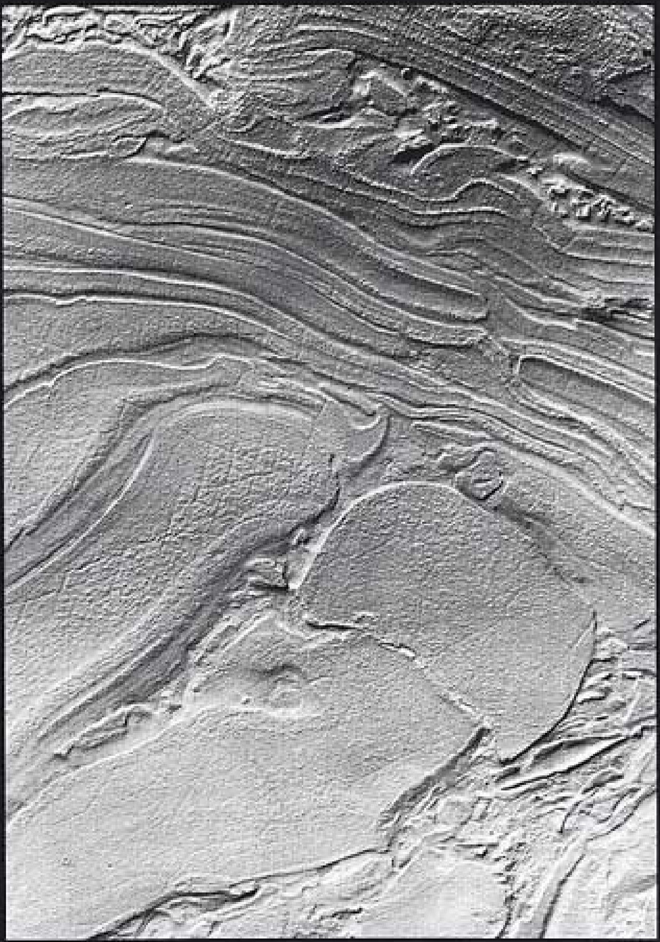
Unconformity in Pollack Crater. The presence of layered rock on Mars has also led to discovery of unconformities—unconformities signify missing time in the rock record due to erosion. (Except where lava flows are present and/or infrared spectra are used to indicate rock composition, no one knows what kind of rocks comprise the Martian geologic record.) This picture shows linear, light-toned ridges enclosed in a larger ancient crater, (named recently for the late NASA Ames Research Center [Moffett Field, California] planetary scientist James B. Pollack). From a geologic perspective, what is most striking about this picture is an outline of the raised rim of an impact crater (arrows). The crater is covered by the dark, rippled sand and the light-toned ridge-forming rock, which tells us an unconformity exists representing as unknown span between the time that the rock into which the crater formed and the overlying light-toned butte-forming rock was deposited. This picture covers an area 3.0 by 4.6 km and is illuminated from the upper left. Subframe of MOC image M19-00309, near 8.1°S, 334.9°W.

WATER ON MARS?

Valley Meandering Between Massif and Crater in Libya Montes. For nearly 3 decades we have known that Mars has numerous networks of small valleys on its surface. They occur in the oldest, most cratered terrain of Mars, and thus have been taken by most investigators to indicate where fluid erosion—most likely, water erosion—occurred early in the planet's history. MOC images have revealed that many of these valleys may have formed underground and/or were buried for some time, and later only partly exhumed (Malin and Carr, 1999). The networks seen in most MOC narrow angle camera images are discontinuous, and there are no smaller valleys feeding into the larger ones that would indicate surface runoff (Carr and Malin, 2000). One example of a small Martian valley is shown here; this occurs among 1- to 3-km-high mountains on the southern rim of the ancient Isidis impact basin and meanders between an approximately 3-km-diameter impact crater and a small hill. Located near 1.5°N, 278.4°W and illuminated from the left, this picture covers an area 3.0 by 6.7 km, subframe of M02-04206. The color is artificial, derived from observed by the MOC wide angle cameras.

Water-lain debris? This light-toned apron occurs at the end of a channel carved in the inner walls of an impact crater at 37.4°S, 168.1°W near Gorgonum Chaos in the Martian southern hemisphere. The apron is composed of multiple, overlapping lobes formed from many pulses of debris that traveled down through the channel, which migrated across the slope over time. The channel seen here, pointing toward the bottom of the image, migrated from one that pointed toward the lower right. This apron appears to be relatively fresh; there are no mantles of dust or sand to cover it up, no small impact craters to indicate that it is old. Like the gullies found elsewhere on Mars, this apron is among hundreds of landforms in the middle and polar latitudes that may indicate the presence of modern reservoirs of Martian groundwater (Malin and Edgett, 2000). Illuminated from the left, subframe of M14-01830, and covers an area about 1.5 by 2.0 km.





JUST WHEN YOU THOUGHT IT WAS MAKING SENSE

Platy landscape in Mars' northwest Hellas Planitia region. The seeming familiarity of many of the pictures we have presented here might give the impression that it is pretty easy to understand what the MOC has revealed about the geology of Mars. Indeed, much of what has been found is both interpretable and profound: layers recording the planet's early geologic history, evidence for recent groundwater emerging at the surface, dust storms and frost patterns indicating seasonal change. However, many Martian landforms remain unexplained. This is a difficult task using our "Terra-centric" experience alone. This picture (left), acquired in late October 2000, appears to be a jumble of plates or layers exposed at the surface but subsequently covered by a thin mantle to give the scene a uniform brightness. Sunlight illuminates from the upper left. However, we could be wrong. At the time of this writing, the landscape of northwestern Hellas Planitia, along with the bizarre "swiss cheese" features of the Martian south polar cap, are among the most difficult to explain. Subframe of image M20-01277, it covers an area 2.9 by 4.1 km near 39.7°S, 306.7°W.

REFERENCES

Bandfield, J.L., Hamilton, V.E. and Christensen, P.R., 2000, A global view of Martian surface compositions from MGS-TES: Science, v. 287, p. 1626-1630.

Carr, M.H. and Malin, M.C., 2000, Meter-scale characteristics of Martian channels and valleys: Icarus, v. 146, p. 366-386.

Hodges, C.A. and Moore, H.J., 1994, Atlas of volcanic landforms on Mars: U.S. Geological Survey Professional Paper 1534, p. 63.

Malin, M.C. and Carr, M.H., 1999, Groundwater formation of Martian valleys: Nature, v. 397, 589-591.

Malin, M.C. and Edgett, K.S., 2000, Evidence for recent groundwater seepage and surface runoff on Mars: Science, v. 288, p. 2330-2335.

Malin, M.C., Carr, M.H., Danielson, G.E., Davies, M.E., Hartmann, W.K., Ingersoll, A.P., James, P.B., Masursky, H., McEwen, A.S., Soderblom, L.A., Thomas, P., Veverka, J., Caplinger, M.A., Ravine, M.A., Soulanille, T.A. and Warren, J.L., 1998, Early views of the Martian surface from the Mars Orbiter Camera of the Mars Global Surveyor: Science, v. 279, 1681-1685.

McEwen, A.S., Malin, M.C., Carr, M.H. and Hartmann, W.K., 1999, Voluminous volcanism on early Mars revealed in Valles Marineri: Nature, v. 397, 584-586.

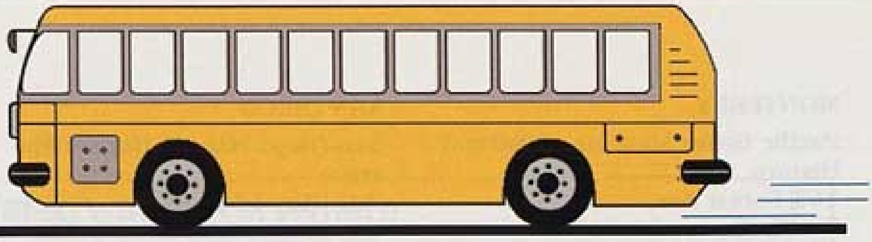
Thomas, P.C., Malin, M.C., Edgett, K.S., Carr, M.H., Hartmann, W.K., Ingersoll, A.P., James, P.B., Soderblom, L.A., Veverka, J. and Sullivan, R., 2000, North-south geological differences between the residual polar caps on Mars: Nature, v. 404, p. 161-164, p. 1.

AUTHORS

Kenneth S. Edgett is a staff scientist at Malin Space Science Systems, San Diego, California. His primary responsibility since he began work there in February 1998 has been to select targets for the Mars Global Surveyor Mars Orbiter Camera and assess the results. Edgett obtained a Ph.D. at Arizona State University, Tempe in 1994. With co-author Peggy Wethered and illustrator Michael Chesworth, he published a children's book, *Touchdown Mars*! (G.P. Putnam Sons, New York, 2000). From 1992 to early 1998 he was director of the Arizona Mars K-12 Education Program and since 1998 he has been "the science guy" for *Brainstorm*, a children's Saturday morning television program that airs in the Phoenix, Arizona area.

Michael C. Malin is the Principal Investigator of the Mars Global Surveyor Mars Orbiter Camera experiment, and President of Malin Space Science Systems. Malin was also the Principal Investigator for cameras that were aboard NASA's lost Martian spacecraft, Mars Observer, Mars Climate Orbiter, and Mars Polar Lander. Malin's company builds and operates cameras that fly aboard spacecraft, including a visible imaging subsystem for the 2001 Mars Odyssey orbiter that will launch in April. Malin received his Ph.D. from Caltech in 1976 and has conducted field research in Antarctica, Iceland, Hawaii, and at Mount St. Helens. Malin received the prestigious MacArthur Fellowship in 1987.

Teacher Feature



Southern California Museums

These are selected California museums (listed by county) that feature earth science; science and technology; mining; and oil & gas exploration. Many are natural history museums that include local paleontology and mineral exhibits. Because hours of operation are highly variable, it is advisable to call the museum before visiting.

INYO

Borax Museum
P.O. Box 1
Death Valley, CA 92328
(760) 786-2345

Located in Furnace Creek, Death Valley, the museum contains an extensive collection of local rocks and minerals. Highlights the borate minerals and mining artifacts from the early Borax Mine.

Shoshone Museum
P.O. Box 38
Shoshone, CA 92384
(760) 852-4414

Museum curators aim to expand this small museum to include exhibits on the natural history of the area. Majority of current exhibits highlights local pioneers; however the collection of local rocks, minerals and fossils is growing. Current exhibits teach about local geologic formations and paleontological collections, which include mammoth remains and casts of ancient animal footprints.

KERN

Buena Vista Museum of Natural History
1201 20th St.
Bakersfield, CA 93301
(661) 324-6350
www.sharktoothhill.com

The specific purpose of the Buena Vista Museum is to promote the scientific and educational aspects of earth history, particularly paleontology and anthropology. This is done through workshops, field trips and other events that educate the public about regional geology. Though the museum specializes in local Miocene vertebrate fossils, invertebrate fauna is well represented in the fossil record and in the museum.

Maturango Museum
100 E. Las Flores Ave
Ridgecrest, CA 93555
(760) 375-6900
www.maturango.org

Natural history exhibits that include diagrams of volcanic activity in the nearby Coso range; video about geothermal energy, and rocks of the area; paleontology - mammoth and bison bones from China Lake, mural of mammoths; Pleistocene lakes map shows extent of lakes 10,000 years ago.

Tehachapi Museum
310 South Green Street
P.O. Box 54
Tehachapi, CA 93581
(661) 822-8152

A natural history museum that includes fossils, rocks and outdoor mining equipment exhibits. Also has extensive collection of newspaper accounts on area's history, which include several natural disasters and the 1952 Tehachapi earthquake.

West Kern Oil Museum
1168 Wood Street
Taft, CA 93268
(805) 765-6664
www.westkern-oilmuseum.org/

Artifacts and displays of the area's oil and cultural history. Outdoor exhibits include a working wooden oil derrick and oil field equipment. The grounds are landscaped with native California plants. Original oil industry technology on display. Museum offers group tours.

LOS ANGELES

George C. Page Museum of La Brea Discoveries
5801 Wilshire Blvd.
Los Angeles, CA 90036
(323) 934-7243
www.tarpits.org

The Page Museum is one of the world's most famous fossil localities, recognized for having the largest and most diverse assemblage of extinct Ice Age plants and animals in the world. Visitors can learn about Los Angeles as it was between 10,000 and 40,000 years ago, during the last Ice Age, when animals such as sabertooth cats and mammoths roamed the Los Angeles Basin. Through windows at the Fossil Preparation Laboratory, visitors can watch bones being cleaned and repaired. Outside the museum in Hancock Park, life-size replicas of several extinct mammals are featured. Tours, workshops and visiting fossil collector are available. For educational programs call (323) 857-6306.

Natural History Museum of Los Angeles County
900 Exposition Blvd.
Los Angeles, CA 90007
(213) 763-3515
For educational programs call (213) 763-3534.
www.nhm.org

The Mineral Science Department serves to develop and conserve collections of minerals, rocks, and gems and to make these available to the scientific community and the public. Their mineral exhibits comprise some of the finest gems and minerals in the world. Mineral lectures and field trips are offered. The Invertebrate Paleontology collection has over 3.5 million specimens in more than 26,000 cataloged localities. Paleontological exhibits include a cast of the largest known ammonite; invertebrate fossils; and several specimens of amber (fossilized tree sap) with insect inclusions from the Oligocene (23-36 my). Another exhibit includes "What is a fossil?" featuring giant oysters; corals; mollusk shell casts & molds; worm tubes; burrows and many others. Guided tours for K-12 classes, teacher resources and mobile exhibits are included in the museum's educational programs.

MONTEREY

Pacific Grove Museum of Natural History
165 Forest Ave.
Pacific Grove, CA 93950
(831) 648-5716
www.pgmuseum.org/

In addition to displays on the plant and animal life of Monterey County, there is also a large exhibit on the county's geology, paleontology, and mineralogy. The museum's Education Outreach Program provides speakers for classroom. Group tours.

ORANGE

Ralph B. Clark Interpretive Center
8800 Rosecrans Ave.
Buena Park, CA 90621
(714) 870-8045
www.ocparks.com/clarkpark/

Located in Ralph B. Clark Regional Park, the interpretive center provides an educational view of prehistoric Orange County through displays, programs and guided tours. It also provides visitors a chance to see scientists and volunteers excavate and prepare fossil specimens for study and display.

RIVERSIDE

Palm Springs Desert Museum
101 Museum Drive
Palm Springs, CA 92262
(760) 325-7186
www.psmuseum.org

Among its other arts and natural science exhibits, the museum has various permanent and periodic exhibits of local geology and ancient life of southern California.

SAN BERNARDINO

San Bernardino County Museum
2024 Orange Tree Lane,
Redlands, CA 92374
(909) 307-2669
www.co.san-bernardino.ca.us/museum/

The museum's section of geological sciences includes an extensive collection of fossils, rocks and minerals of the region. It also includes a library of geological references, periodicals, journals, and other science literature. The museum holds more than half a million fossils of extinct vertebrates and invertebrates, primarily from the southwestern United States, with an emphasis on San Bernardino and Riverside counties. Group tours, special educational programs, and teacher resources are offered.

SAN DIEGO

San Diego Natural History Museum
P.O. Box 121390
San Diego, CA 92112-1390
(619) 232-3821, ext. 216
www.sdnhm.org/about/ourmuse.html

The museum's extensive mineral collection is highlighted at the Josephine L. Scripps Hall of Mineralogy and in a realistic walk-through mine tunnel containing "pockets" of local gemstones, and in interactive exhibits that explore properties of gems and minerals, such as crystal growth, radioactivity and mineral fluorescence. Locally found fossils are currently exhibited in the Bruder Family Mineral Gallery, and The Parker Foundation Discovery Lab features an interactive videodisc about geology, volcanoes, earthquakes, and a visual mineral dictionary. A real-time seismograph continuously records local earthquake activity, with interpretive printouts and explanations of plate tectonics. The museum's educational department provides lectures, classes, field trips and teacher resources.

SANTA BARBARA

Santa Barbara Museum of Natural History
2559 Puesta del Sol Road
Santa Barbara, CA 93105
(805) 682-4711
www.sbnature.org/

The Geology and Paleontology Hall contains information on the formation and history of the region. Among the unique and important fossils exhibited here are the giant "toothed" bird, a giant toothed whale, and the Channel Islands pygmy mammoths. The Research Library and Archives of the Museum are filled with invaluable resources concerning the natural and cultural resources of the region. The library collections include many important works on geology, anthropology, archaeology, and zoology.

VENTURA

California Oil Museum
P.O. Box 48
1001 E. Main St.
Santa Paula, CA 93061
(805) 933-0076
www.oilmuseum.net

The museum presents both permanent and changing exhibits. The permanent exhibits explain the workings of the petroleum industry and its history in California. The changing exhibits focus on art, history, and science and are presented throughout the year. Please call for schedules. The workings of the oil business are explained through video programs, interactive models, games, artifacts, photographs, and a variety of historical memorabilia. Other exhibits include an authentic turn-of-the-century, working cable-tool oil rig. The offices have been restored to reflect the original 1890 appearance of Union Oil Company's first corporate headquarters. Daily tours offered.

California and U.S. Collections

Public exhibits, some with significant fossil or mineral collections, can also be seen at many of the visitor centers in state parks, national parks and national forests in California. For information, contact the following headquarters:

California Department of Parks and Recreation
P.O. Box 942896
Sacramento, CA 94296-0001
(916) 653-6995
www.parks.ca.gov/

The California State Office of the National Park Service
600 Harrison St., Suite 600
San Francisco, CA 94107
(415) 427-1300
www.nps.gov/

US Forest Service, Pacific Southwest Region
1323 Club Drive
Vallejo, CA 94592
707-562-USFS
www.fs.fed.us/recreation/states/ca.shtml

Photo by Bob Ross.

San Diego Natural History Museum amethyst crystals.

NWSEb.explorer

Water, water everywhere

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